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Soil deepening by trees and the effects of parent material

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ABSTRACT

In some cases biomechanical effects of individual trees may locally deepen or thicken regolith, especially in relatively shallow soils. This biogeomorphic ecosystem engineering phenomenon is at least partly contingent on the geological setting. The purpose of this research was to gain further insight into the biogeomorphic phenomenon, and to assess the relative importance of biomechanical and geological effects. Earlier studies in the Ouachita Mountains of Arkansas showed that individual trees locally thicken the regolith via mechanisms associated with root penetration of bedrock. However, that work was conducted mainly in areas of strongly dipping and contorted rock, where joints and bedding planes susceptible to root penetration were thought to be common and accessible. This project extended the research to the Cumberland Plateau region of Kentucky, where flat, level-bedded sedimentary rocks are dominant. Soil depth beneath trees was compared to that of non-tree sites by measuring depth to bedrock beneath rotted tree stumps and at adjacent sites with 1.0 m. While soil thickness beneath stumps was greater in the Ouachita Mountains compared to the Kentucky sites, in both regions soils beneath stumps are significantly deeper than adjacent soils. Further, there were no statistically significant differences in the difference between stump and adjacent sites between the two regions. This suggests the local deepening effects of trees occur in flat-bedded as well as steeply dipping lithologies.

1. Introduction

When tree roots penetrate bedrock joints, fractures, and bedding planes (hereafter just joints, for brevity) they can locally increase regolith and soil thickness in several ways (e.g. Johnson, 1985; Johnson et al., 2005; Phillips et al., 2005a, 2008, 2015; Phillips and Marion, 2005, 2006; Bashan et al., 2006; Schwinning, 2010; Estrada-Medina et al., 2013; Pawlik, 2013). Pressure of root growth within joints can widen them (Gabet et al., 2003), allowing eventual infilling by soil, sediment, and organic matter (Phillips et al., 2005a). Roots can also attach themselves to rock fragments in the bedrock or at the weathering front, sometimes encircling them. Uprooting of trees can then "mine" bedrock (Ulanova, 2000; Phillips et al., 2005a). Trees and roots penetrating to and into bedrock facilitate infilling with unconsolidated material after tree death and decomposition (Phillips, 2008). Roots (and root channels after decomposition) also focus preferential water flow, facilitating both physical transport and chemical weathering processes (Gabet et al., 2003). Finally, the moisture fluxes, respiration, organic decomposition, and organic acid formation by roots and microbes in the rhizosphere may locally accelerate chemical weathering within the occupied joints (Yatsu, 1988; Jones, 1998). Though the latter mechanisms include biochemical processes, these phenomena are lumped together here under the term biomechanical effects.

Of the limited research that has been conducted on the biomechanical effects of trees, most has focused on tree uprooting (e.g. Johnson, 1990; Gabet and Mudd, 2010; Šamonil et al., 2010). It is well known that tree uprooting is a mechanism by which rocks or rock fragments are brought to the surface (Lutz, 1960; Ulanova, 2000; Phillips et al., 2005a, 2005b; Osterkamp et al., 2006). If the tree is anchored in bedrock it is possible for fragments of parent material to be transported vertically and horizontally as part of the root wad. This is an important indicator of biomechanical weathering, via root/bedrock interaction, that can be observed in the field. While tree uprooting has significant impacts to soil characteristics, it is the interaction of roots with bedrock that directly facilitates the biomechanical deepening of soil. Lutz (1960) reviewed some of the earliest examples of research on root penetration, where tree roots grew several meters into sandstone and granite. Phillips and Marion (2004, 2005) suggested that trees growing on soils formed from weathered bedrock may play a significant role in local deepening and mixing of soil by facilitating weathering in joints occupied by roots. They showed that soil underlying individual tree locations were systematically deeper or thicker than at adjacent locations in the shallow forested soils of the Ouachita Mountains (Phillips and Marion, 2004; Phillips, 2008). Gabet and Mudd (2010) considered this microtopographical variation due to root fracture when simulating the production of soil from bare rock. Through computer simulation based

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on empirical data they demonstrated that root fracture, a term used to describe the occupation of roots in bedrock fractures, leads to a rough and uneven bedrock surface.

As soil thickness is a critical edaphic factor for plants, these biogeomorphic tree effects are by definition, a form of ecosystem engineering. However, these effects are by no means inevitable. The self-reinforcing pedologic influences of trees (SRPIT) conceptual model proposed by Phillips (2008) explained some of the conditions required for local deepening to occur. First, trees must inhabit areas where regolith is thinner than the typical rooting depth of the trees. Phillips and Marion (2004, 2005) suggested that individual trees may "engineer" sites to produce relatively thicker soil when thickness is less than the preferred or optimum rooting depth. Second, as the mechanisms of regolith deepening depend on root-rock interactions, geological control (structure and lithology) is also significant to this process (Phillips, 2008). Phillips (2008) conducted his research in sedimentary rocks affected by intense tectonic deformation (Ouachita Mountains), such that joints and fractures are common and bedding planes are steeply dipping (30° to near-vertical). These structural characteristics presumably facilitate root penetration of bedrock by providing numerous rock partings potentially exposed to root penetration from above. In this system Phillips (2008) found that soil directly beneath sites recently occupied by trees was deeper than at adjacent sites within 1.0 m 91% of time.

This raises the question of the extent to which similar processes occur in an area of comparable lithology, but horizontally bedded and undeformed. This study compares soil thickness related to biomechanical effects of trees in horizontally-bedded sedimentary rocks of the Cumberland Plateau, to those of the Ouachita Mountains, Arkansas, to address this question, and also to shed light on the relative importance of biogeomorphic effects and parent material variability on spatial variations of soil and regolith thickness. Thus, this research tests the hypothesis of systematically deeper soils beneath trees in a different geologic setting, the Cumberland Plateau, where bedrock is composed of flat-bedded sedimentary rocks, which presumably offer less opportunity for roots to penetrate bedrock. If soil is systematically deeper beneath trees in the horizontally bedded rocks, it will suggest that the biomechanical effects of trees can operate independently of the geological conditions found in the Ouachitas. Otherwise, a major role for lithological and structural variability of parent material is indicated. In this particular situation, lithological and structural variability are closely related in that the strongly dipping and contorted strata of the Ouachitas leads to local-scale variation in lithologies exposed at the surface. In the Cumberland Plateau, by contrast, surface lithological variation occurs only where incision has exposed different formations along slopes. This analysis was based on the assumption that soil depth differences between stumps and adjacent sites are primarily due to tree effects. We also recognize that a number of factors other than biomechanical effects of trees and parent material variability may influence soil depth (Johnson, 1985; Johnson et al., 2005; Phillips et al., 2005b).

2. Study area and methods

2.1. Study areas

Study sites are in the Ouachita Mountains and the Cumberland Plateau physiographic regions (Fig. 1). Within the Ouachitas, sampling took place in the eastern Ouachita National Forest.

Within the Cumberland Plateau, sampling was conducted in the Koomer Ridge section of Daniel Boone National Forest and the Indian Trails section of Berea College Forest. While both the Ouachitas and Cumberland Plateau are characterized by Paleozoic sedimentary rocks dominated by sandstones and shales, the two regions differ greatly in their structural characteristics. Strata in the Ouachita Mountains are strongly dipping and contorted and in many areas oriented near-vertical. The sedimentary rocks in the Cumberland Plateau are flat-bedded and presumably offer less opportunity for roots to penetrate bedrock, as bedding planes are not accessible to penetration from above. Fig. 2 shows a comparison of each situation.

2.1.1. Ouachita Mountains

The Ouachita Mountains are an east-west trending folded mountain range in west central Arkansas and southeastern Oklahoma, with elevations ranging from 230 m to 839 m. This research took place within the Ouachita National Forest (ONF) (34°29′45″ north, 94°07′30″ west). The Ouachita Mountains have a humid subtropical climate and a mean annual precipitation of about 1200 mm yr^{-1}. Average daily summer and winter temperature ranges are 20–30 °C and 4–10 °C, respectively. Forest cover is dominated by shortleaf pine (*Pinus echinata*) and various oak species (*Quercus* sp.).

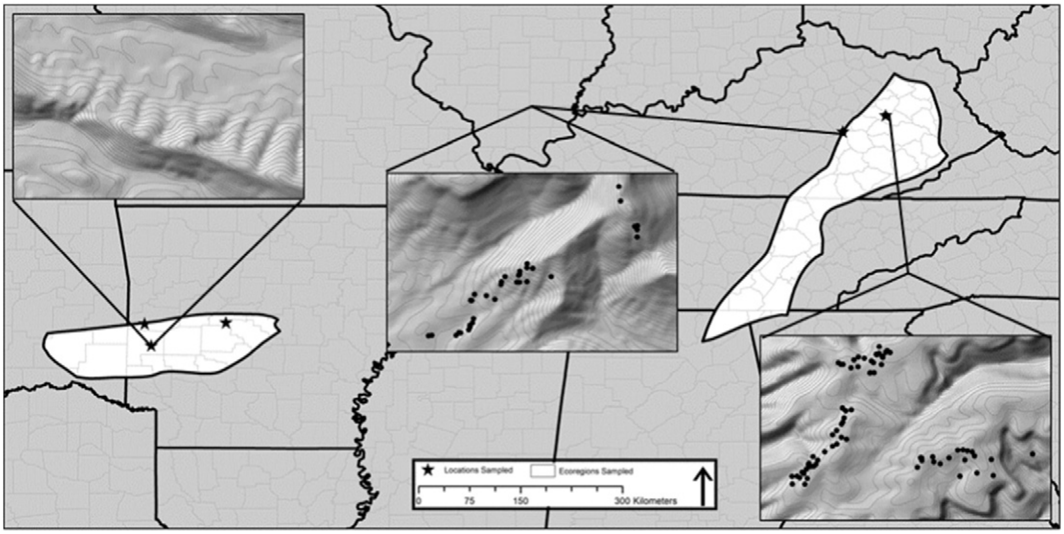

Fig. 1. This figure shows the sampling locations in the Ouachita Mountains (Arkansas, Oklahoma) and the Cumberland Plateau (Kentucky, Tennessee) physiographic regions. The breakout views show a closer view of the sample locations at the same spatial scale; underlain with standardized contour lines and hillshades derived from the USGS National Elevation Dataset. The breakout views from the Cumberland Plateau show a sample of stump-pair locations from this study. Specific locations of stump-pairs in the Ouachita Mountains were not recorded in previous studies and could not be replicated here.