What is the effect of loess on soil catena evolution in the Midwestern United States?

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Abstract

We investigate the influence of loess on soil catena development, specifically, soil morphological expression and biogeochemical processes associated with profile development. Loess has a positive impact on solum thickness and development of clay-enriched subsoil horizons. Abundant pore space and reactive surface area associated with the high silt and clay content and smectitic clay mineralogy of the loess in our study areas aids moisture retention, biogeochemical transformations and translocation of Fe and P, and storage of C, especially with increasing carbonate mineral content.

Key Words

Colluvium, Alfisols, Mollisols

Introduction

In the Midwestern United States loess accumulated on land surfaces not covered by glaciers and also on some glaciated land surfaces following exposure from beneath the ice. In most areas, the loess was redistributed down slopes, leading to a patchwork in which parts of the landscape have thick loess, thin loess, or no loess at all. The hypothesis tested in this project is that the thickness of loess remaining in a given location has a major influence on soil development because of the distinctive properties of the loess, which should favor high moisture and nutrient retention and rapid formation of clay-rich subsoil horizons.

In this paper we investigate the influence of loess on soil catena evolution in two distinct landscape types in the Midwest. Our study areas include (1) the steeply sloping bluff lands of the Upper Mississippi Valley in southeastern Minnesota, where slopes consist of Pleistocene periglacial slope deposits (colluvium) that vary in the proportion of mixed loess and carbonate bedrock or sandstone bedrock, and (2) the glaciated land surface of the Green Bay Lobe in south-central Wisconsin that has landscape characterics varying from steeply sloping drumlinized terrain to low relief till and outwash plains.

Methods

Soil catenas on the Green Bay Lobe land surface were sampled using a Giddings hydraulic soil corer, extracting 7.6 cm cores. Colluvial soil catenas in the bluff lands were sampled from outcrops created by recent excavations for logging roads. Soils were described using standard terminology and sampled by genetic horizon for laboratory analysis. Lab analyses followed standard methods and included: particle size analysis by pipet and sieve and laser diffraction, soil organic carbon (SOC) by loss-on-ignition, pH using 1:1 soil-water paste, Fe oxyhydroxides by dithionite and oxalate extractions and analyzed by atomic absorption, P fractions by sequential extractions, base cations, acidity and ECEC by ammonium acetate and KCl extractions, and clay (<2 µm) and silt (8-63 µm) mineralogy by x-ray diffraction.

Results

Minnesota Bluff Lands

The soils at our Cut Across Road research site occur on a steep slope underlain by bedrock at a fairly shallow depth, including dolomite of the Prairie du Chien Group (Ordovician) underlying the upper part of the slope, and sandstone of the Jordan Formation (Cambrian) beneath the lower slope. All of the soils that were sampled formed from various mixtures of loess and weathered bedrock. The loess is dominated by silt, but contains significant amounts of smectite clays (Mason *et al.* 1994). Both of these materials have been moved some distance downslope by erosion and deposition, primarily during the last glacial period, from about 25,000 to 11,500 years ago.

The soils can be divided into three groups. Silt-rich Group 1 soils on the very gently sloping, lowest part of the slope are formed mainly from redistributed loess, with some sand input from weathered sandstone. These silty soils have not yet been studied in detail. Higher on the concave lower slope, Group 2 soils are formed predominantly in sand weathered from sandstone, though with a silty loess-derived layer in one profile. These sandy soils have acidic upper horizons and low contents of organic carbon that is concentrated in a thin A horizon, and relatively low water retention and potential to supply nutrients. Group 3 soils occur on the steep, convex upper slope, and have upper horizons formed in a mixture of loess and dolomite rock fragments. Near the ridgetop, subsoil horizons are formed in the same material, but farther downhill, subsoils are formed from weathered sandstone. All of these upper slope soils have neutral to alkaline pH and have silt- and smectitic clay-rich near-surface horizons that have relatively high potential to store SOC (Figure 1). Many of the upper slope soils contain abundant organic carbon and phosphorus (mainly in organic matter). While all of these properties may suggest that the upper slope soils are favorable for high plant productivity, availability of some nutrients may actually be seriously limited by high pH, slow organic matter decomposition, and low total volume of water storage because of abundant rock fragments.

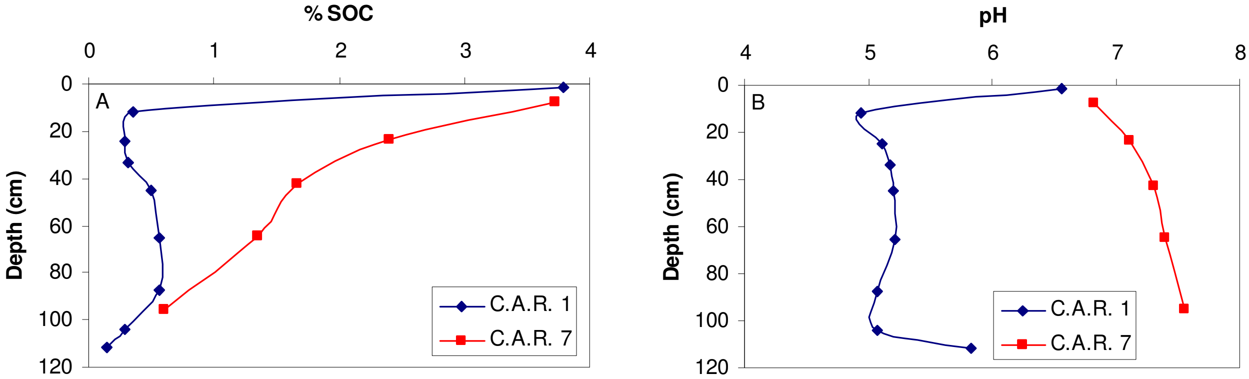

Figure 1. Profile distribution of SOC and pH in soils in Groups 2 and 3. Group 2 soils (C.A.R. 1) have low silt and carbonate bedrock content and are acid, and store less SOC than Group 3 soils (C.A.R. 7) with higher silt and carbonate bedrock components.

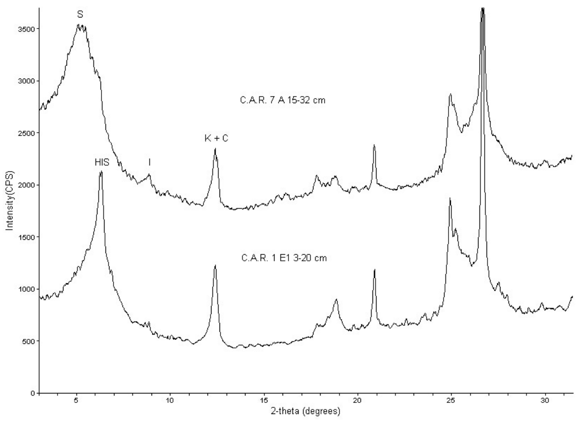

Figure 2. X-ray diffractograms of <2 µm clay minerals from soil profiles formed in sandy colluvium with minimal loess (C.A.R. 1) and mixed loess and dolomitic colluvium (C.A.R. 7). Note the strong 1.4 nm peak associated with the acidified sandy colluvium, while the minimally acidified C.A.R 7 sample retains the distinctive smectite peak characteristic of loess. Heat treatments (not shown) confirm the presence of HIS/HIV. Samples were Mg saturated and ethylene glycol solvated; S=smectite, HIS=hydroxy interlayered smectite, I=illite, and K+C=kaolinite plus chlorite.

C.A.R. 1 is acidic throughout the profile (Figure 1), especially below the thin A horizon, making clay, iron, and phosphorus mobile within the soil. Clay coatings and iron oxides have been translocated from a relatively thick (38 cm) eluvial upper solum to the Bt horizon. In contrast, the degree of acidification in C.A.R. 7 is minimal, and dolomite is still present in the silt fraction. Profile morphology consists of a series of dark horizons (A/AB/Bw) with minimal evidence of clay translocation. Clay mineral weathering is not detectable in C.A.R. 7, while in the acid profile C.A.R 1, smectite has developed hydroxy interlayers (Figure 2).

Green Bay Lobe

Soils on the Green Bay Lobe land surface have formed in a range of loess thickness from zero to nearly two meters overlying glacial sediment. Loess accumulated following deglaciation of the region. Regional thickness and grain-size fining patterns indicate the source of the loess was largely the drained bed of Glacial Lake Wisconsin, along with clays from sources further west, based on the content of smectite clay minerals. Much of the loess accumulated between 14,000-10,600 cal yrs BP, based on optical stimulated luminescence ages of eolian sand in the source area (Rawling *et al.* 2008), although this project reports some sand dunes on the Green Bay Lobe land surface were active until at least 9500 cal yrs BP.

Following deposition, loess was commonly redistributed in the landscape, with steeper slopes retaining minimal to no loess. Most of the redistributed loess accumulated in foot slope positions, filling topographic lows between drumlins. In addition, drainage of the underlying landscape apparently affected loess redistribution, with permeable outwash deposits or fractured bedrock uplands retaining uniformly greater thickness of loess. Thickness patterns of loess strongly impact the uniformity of mapped soil patterns and profile characteristics such as solum thickness and Bt horizon expression.

For example, flat outwash plains abandoned as terraces accumulated loess with minimal redistribution and soil surveys show large soil bodies with similar profile characteristics. A catena transect across a former braid channel demonstrated minimal variation in loess thickness and only slight changes in soil morphology associated with increased wetness in the braid channel. In drumlinized terrain, the loess was redistributed into the intervening lowlands, and soils are formed in loess and till on summit and backslope positions, while in footslope positions the entire solum is contained within loess (Figure 3).

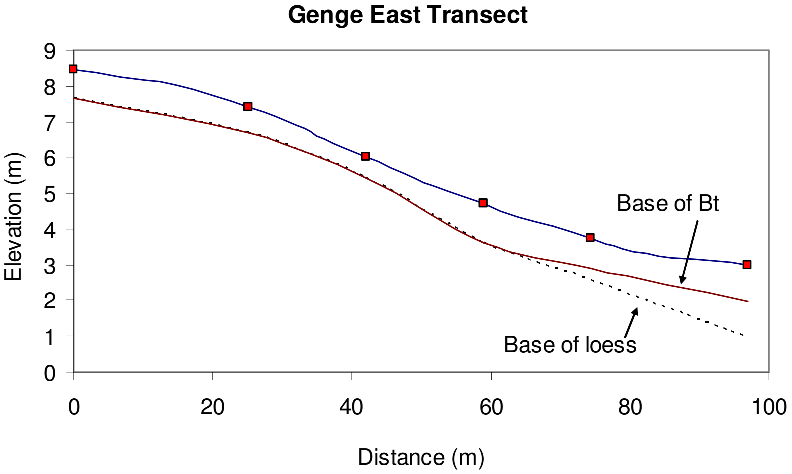

Figure 3. Cross section along a drumlin hillslope illustrating surface elevation, location of profile descriptions (■) field-identified thickness of loess mantle, and base of Bt horizon. Note coincidence of loess mantle and Bt horizon expression, while in footslope position loess thickness exceeds Bt thickness.

The influence of the loess mantle on profile expression is illustrated in Figure 4, where thickness of the loess mantle has a clear impact on the thickness of the solum and to a lesser extent the thickness of Bt horizons. Clay enriched subsoil (Bt) horizons occur in nearly all soils on the Green Bay Lobe land surface. The presence of illuvial upper sola is largely a function of native vegetation, with only forest areas typically having relatively thick E horizons. Clay minerals in the loess are dominated by smectite (Figure 5).

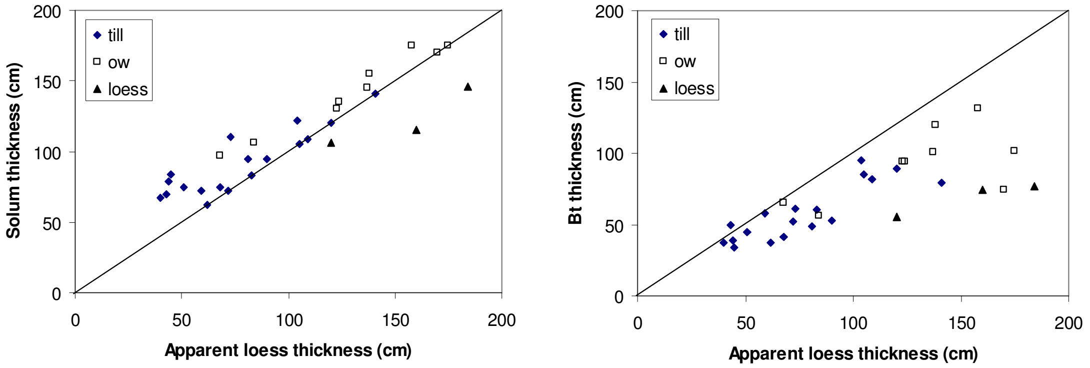

Figure 4. (Left) solum thickness as a function of loess thickness follows a near 1:1 relationship in soil formed in a mantle of loess over till, outwash, or entirely in loess. Note in most instances solum thickness exceeds thickness of the loess mantle because soil formation has transgressed the lithologic discontinuity. (Right) Thickness of Bt horizons increase as loess thickness increases, although at a lesser rate than solum thickness.

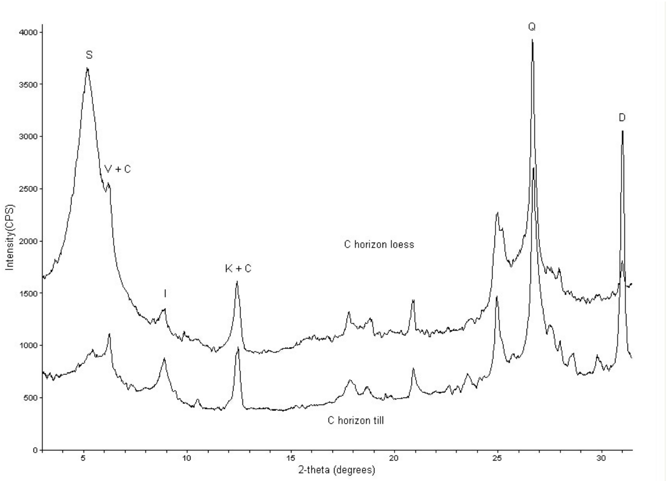

Figure 5. X-ray diffractograms of <2 µm clay minerals from C horizons in loess (upper) and till (lower) on the Green Bay Lobe land surface. Note the distinctive peak associated with smectite in loess, while till has greater amounts of illite and kaolinite, along with very abundant dolomite (in all size fractions). Samples were Mg saturated and ethylene glycol solvated; S=smectite, V+C=vermiculite plus chlorite, I=illite, K+C=kaolinite plus chlorite, Q=quartz, and D=dolomite.

Discussion

Loess is a widespread soil parent material of soils of the mid-continent of North America and elsewhere. Redistribution of loess under periglacial climate conditions established the parent materials for soil formation and much of the geographic variability of solum thickness and morphology in catenas of the upper Midwest U.S. The abundance of silt and smectite clay in loess deposits provides abundant pore space and reactive surfaces for soil formation and ecosystem processes. Increasing content or thickness of loess in soils, especially in the presence of carbonate minerals greatly enhances soil storage of water, SOC, nutrients, and buffering against acidification.

References

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