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Coarse-textured basal zones in thin loess deposits: Products of sediment mixing and/or paleoenvironmental change?

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ABSTRACT

The purpose of this research was to characterize and interpret the coarse basal zones that are common in thin loess deposits that overlie coarser-textured sediment. To that end, we sampled nine pedons in northeastern Wisconsin and the Upper Peninsula of Michigan, each of which had formed in thin (≤55 cm) loess over sandy glacial sediment. At most of these sites, the loess became noticeably coarser near the lithologic discontinuity. The loess has a primary particle size mode in the coarse silt or fine, very fine sand fraction (≈30–65 μm) and a secondary mode in the fine or medium sand fraction (≈200–400 μm). We attribute the secondary mode to mixing of underlying sands into the loess, either during loess deposition or by post-depositional pedoturbation. In thin loess, pedoturbation processes can penetrate into the underlying sediment, facilitating mixing upward as far as 50 cm into the loess. Silt from the loess has also been mixed into the underlying sandy sediment. Alternatively, in some pedons, the loess itself coarsens with depth; the particle size mode for the loess becomes increasingly coarser with depth. This coarsening suggests that, during loess deposition, one or more of the following was occurring: (1) wind velocities were decreasing over time, (2) the textural character of the loess source area(s) were changing/decreasing, or (3) additional source areas—with finer-textured sediment—became more dominant over time. Our research demonstrates the utility of detailed particle size data for detecting and interpreting the paleoenvironmental history of loess. We also document the extent to which pedoturbation can impact the original textural characteristics of loess (or any sediment) that occurs as a thin surficial mantle.

1. Introduction

Most loess deposits are dominantly silt-sized (Bettis et al., 2003; Fehrenbacher et al., 1965; Pye, 1984, 1995; Smalley, 1972, 1990; Wascher et al., 1947); indeed, the silty texture of loess often helps soil mappers, soil scientists and Quaternary geologists identify loess in the field. Loess often occurs in meters-thick accumulations, with silt loam textures dominating nearly the entire loess column (Basarina et al., 2009; Follmer, 1996; Pierce et al., 2011; Roberts et al., 2003; Rousseau and Kukla, 1994; Ruhe, 1984). However, where loess overlies coarser-textured sediment, e.g., till or glacial outwash, the loess is often slightly coarser-textured near its base, e.g., Follmer et al. (1979). That is, silt loam textures within the loess will grade into coarser (or less often, finer; see Frolking et al. (1983)) textures as the lithologic discontinuity between the loess deposit and underlying sediment is approached (Foss and Rust, 1968; Harlan and Franzmeier, 1977; Mason et al., 1994). At and near the discontinuity, textures change not only in the fine earth (<2 mm) fraction, but often in the coarse fraction (>2 mm) as well. This phenomenon is especially common in thin loess deposits (McSweeney et al., 1988; Stanley and Schaetzl, 2011). These "coarse basal zones" in loess deposits can obscure the lower boundary of the loess, making the lithologic discontinuity difficult to determine (Allan and Hole, 1968; Barnhisel et al., 1971; Borchardt et al., 1968; Caldwell and White, 1956). Likewise, these texture changes make it difficult to ascertain the original thickness of the loess unit, and/or the original texture of the earliest loess (Karathanasis and Macneal, 1994; Price et al., 1975).

Coarse textured basal zones in loess are poorly understood and seldom completely described. Loess may be deposited as well-sorted sediment, but mixing processes during the early phases of deposition may cause some of the underlying sediment to be mixed into the loess. If this lower sediment is sandy, these processes will result in a coarse-textured basal zone within the loess. Obviously, not only can the lower sediment be mixed into the overlying loess, but some loess can also be mixed into the underlying sediment, effectively blurring the lithologic discontinuity.

Little is known about the specific pedoturbative processes that mix loess with the underlying sediment, or vice versa. Strong winds may mix the two sediments during deposition, especially on bare ground where the sediment is not held in place by vegetation. Cryoturbation and bioturbation, both of which can mix soils to shallow depths, are the most likely types of mixing processes on cold, wind-blown landscapes (Anderson, 1988; Baker et al., 1991; Caldwell and White, 1956; Johnson et al., 1987; Leigh, 2001; Small et al., 1990). We suggest that

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the extent to which the underlying sediment has been mixed into the loess above, i.e., the thickness of the coarse basal zone, is largely a function of the types and intensities of the pedotubative processes vis-à-vis loess depositional processes. Detailed study of these basal zones may help tease out the significance and strength of each of these sets of processes.

Alternatively some coarse-textured basal zones, or loess particle size curves that are distinctly bimodal in character (Dinghuai et al., 2004), may be due to changing paleoenvironmental conditions, i.e., diminishing wind speeds or changes in source area characteristics, during deposition (Gillette et al., 1974; Muhs and Bettis, 2003; Xiao et al., 1995). For example, Stanley and Schaetzl (2011) believed that the coarser-textured basal zone in a thin loess sheet in Wisconsin formed because of a change in source area; the initial source area was supplying coarser sediment to the loess sheet, but then later, a second, silt-dominated source area, became dominant. Thus, some coarse-textured basal zones in loess may be due to changing paleoenvironmental conditions during deposition, and not to pedoturbation.

Ascertaining the cause(s) and implications of some coarse-textured loess basal zones is a focus of this paper. We report detailed textural data from soils on stable, upland sites in northern Wisconsin and the western Upper Peninsula (UP) of Michigan, where thin loess deposits are widespread, and where they commonly overlie coarse-textured glacial sediment. Particle size data, examined with depth and at nine different sites, are used to infer the processes that produced these coarse-textured basal zones. Although the main purpose of this study is to determine the characteristics and origins of these coarse-textured zones, we also explore the possibility that loess thickness *per se* also impacts the thickness of this mixed zone. For example, in thick loess areas, rapid loess deposition rates may have provided little time for mixing of the two sediments during deposition, thereby minimizing the mixed zone in the basal loess.

The purpose of our research is to determine the extent to which coarse-textured basal zones in thin loess deposits in the study area were formed by (1) pedoturbation of the underlying, coarse-textured glacial sediment into the silty loess column, and/or (2) the initial deposition of coarser-textured loess. Determination of the process(es) by which these coarse-textured zones formed has significant paleoenvironmental implications.

2. Study area

The study area covers much of the western UP of Michigan, with one site in northeastern Wisconsin (Fig. 1). The landscapes were most recently glaciated by the Laurentide ice sheet, with sandy ground moraines, end moraines, and outwash plains being common (Peterson, 1985, 1986). Although incompletely dated because of the general lack of organic material in the glacial sediments (Clayton and Moran, 1982; Clayton et al., 2001), most of these landscapes were likely deglaciated shortly after ≈13.5 ka yr BP, and all were ice-free by ≈ 11.4 ka yr BP (Lowell et al., 1999). Many swampy areas exist interspersed between uplands, and bedrock knobs are especially common in the NE part of the study area. The soils mapped by the Natural Resources Conservation Service (NRCS), in conjunction with county soil survey reports, almost all have sandy C horizons. Most of the

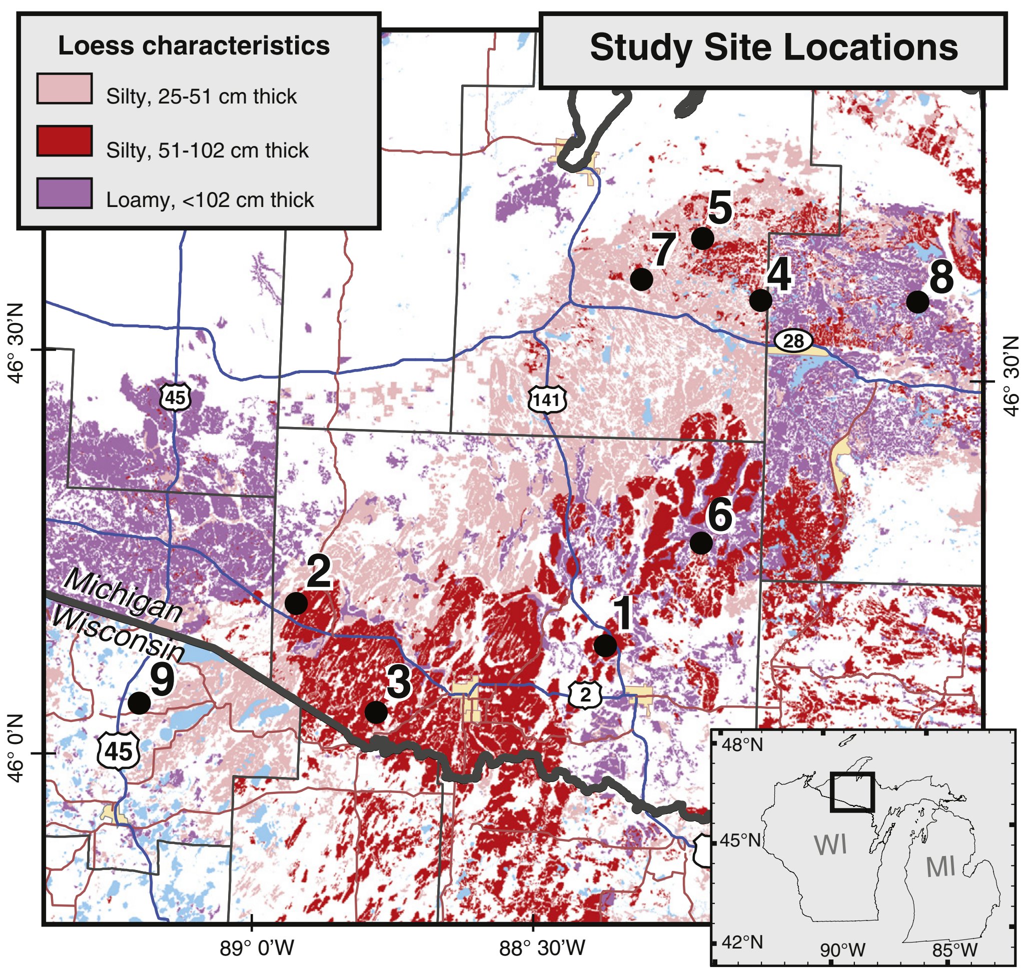

Fig. 1. Extent and thickness of loess across the study area and nearby locations, as determined from NCRS county soil survey maps. Sample site locations and numbers are shown in black.