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Geochemical and mineralogical characteristics of loess along northern Appalachian, USA major river systems appear driven by differences in meltwater source lithology

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ABSTRACT

Eastern United States loess mapped by the U.S. Department of Agriculture, National Resources Conservation Service (USDA-NRCS) mostly occurs near major river systems like the Delaware and Susquehanna Rivers. The proximity of loess along major river valleys suggests late-Quaternary glacial meltwater sediments were dominant sediment sources for loess. Based on differing lithologies of meltwater deposits in these systems, we hypothesize that loess in each river system has a unique geochemical and mineralogical signature. To test this hypothesis, we examined pedons developed in loess parent materials, and adjacent to either the Delaware or West-Branch of the Susquehanna River, both of which carried large amounts of Wisconsinan outwash. Soils were analyzed for particle size distribution, clay mineralogy, and coarse and fine silt particle density, mineralogy, and geochemistry. Results show that while the pedons are similar in morphology, substantial differences exist in the pedons' textures, mineralogies, and geochemical compositions. We attribute the differences to parent material differences that stem from lithologically distinct sediment sources for loess from the two river systems. Susquehanna River loess has a higher particle density, and lower abundance of minerals such as Zr, base oxides (such as CaO), and rare earth elements. Discriminant analysis results suggest that developing a "loess fingerprint" for each river system based on major, minor and rare earth elements is possible, and likely to be useful in differentiating sources; however coarse silts may be a more effective fraction (than fine silts) for sediment sourcing, especially if rare earth elements are used.

1. Introduction

Maps of loess in the eastern United States produced by the U.S. Department of Agriculture, National Resources Conservation Service (USDA-NRCS) mostly occurs near major river systems like the Delaware River (Carey, 1978; Carey et al., 1976) and Susquehanna River (Peltier, 1949; Millette, 1955; Millette and Higbee, 1958; Engel et al., 1996).The proximity of mapped loess along major river valleys suggests that meltwater sediments were dominant sediment sources for loess. The Susquehanna and Delaware Rivers carried substantial meltwater sediments during the Late Wisconsinan (Marine Isotope Stage 2 (Braun, 2011) (Marchand, 1978; Millette, 1955; Peltier, 1959), which would have contributed loess in the winter when water levels had receded and sediments had dried out (Smalley, 1972; Pye, 1984; Smalley et al., 2009; Smalley et al., 2011). Other regional sources of sediments for loess may have included the Delaware and Susquehanna bays near the intersection of Pennsylvania, Maryland, and Delaware (Simonson, 1982). Last, as has been shown in Michigan (Scull and Schaetzel, 2011), sediments for loess may also have been derived from outwash plains, moraines, or glacial lake plains.

1.1. The Susquehanna River basin

Peltier (1949) investigated northcentral Pennsylvania Pleistocene terraces of the Susquehanna River (North and West branches, and main stem) (Fig. 1) and identified loess deposits on terraces adjacent to where the river had carried outwash. Peltier (1949) reasoned that sediment source for the loess deposits were glacial outwash plains and barren till and congeliturbate mantles. Peltier (1949) sourced Wisconsinan gravels on West Branch terraces to lithologies north of the glacial border in Pennsylvania and southern New York (dominantly sandstone and shale). Gravels along the North Branch had similar sources as gravels found along the West Branch, but also gravels reflective of lithologies from farther north (limestone, granite, gneiss, and quartz) in

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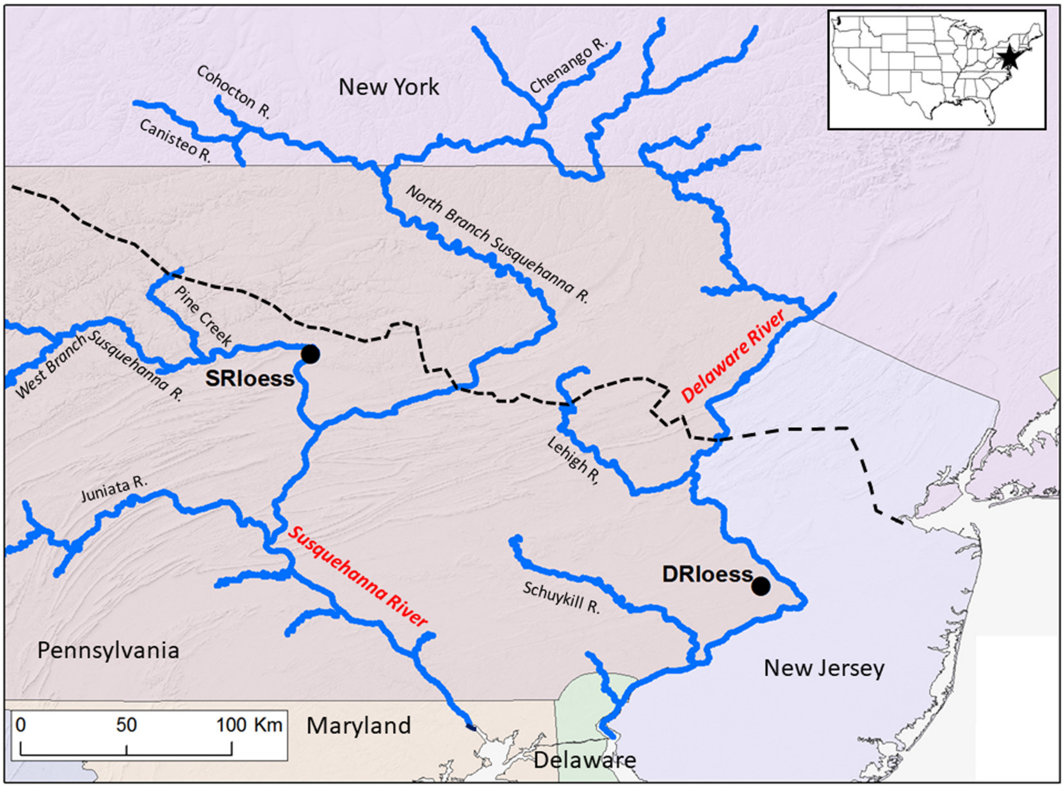

Fig. 1. Inset map shows the conterminous United States and study area (star). Pedon sampling locations (main map) are indicated by black dots: SRLoess (Susquehanna River loess) and DRLoess (Delaware River loess). The Susquehanna and Delaware River systems are noted in heavy blue lines. The Wisconsin boundary of the Lake Champlain-Hudson River lobe (per Braun (1989) and Mickelson and Colgan (2003)) is noted by the heavy, black, dashed line. Gray lines and colored areas indicate U.S. states. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

central and northcentral New York (the Mohawk Valley) and northern New York (the Adirondacks). Peltier (1949) also noted that sands and silts representative of upstream lithologies could often be found farther downstream than gravels of the same lithology; in such locales, gravel would be representative of locally weathered material.

Millette and Higbee (1958) specifically investigated mineralogy and particle shape characteristics of Susquehanna River loess and post-glacial alluvium. They found that the North Branch's mineralogy, in comparison to the main stem near Harrisburg (derived from the West and North Branches), had greater orthoclase, hornblende, tourmaline, and often magnetite, which suggests a source area in central to northern New York.

1.2. The Delaware River basin

Carey et al. (1976) documented the extent of loess across the Delaware River Valley in southeastern Pennsylvania and reasoned that past climate and wind direction suggested the Coastal Plain, Delaware River, and Schuylkill River as potential sediment source areas. Based on the decrease in loess thickness with greater distance north and west across the Delaware River Valley, Carey et al. (1976) concluded that of the three plausible sediment source areas, the Coastal Plain was the most probable. A better understanding of the Wisconsinan glaciation has subsequently emerged since the studies of Carey et al. (1976), and based on current knowledge of the movement of the Lake Champlain-Hudson River glacial lobe in eastern Pennsylvania and New Jersey (Tedrow and MacClintock, 1953; Braun, 2004) and the potential importance of meltwater sediments in influencing Susquehanna River loess, the Delaware River meltwater sediments seem the most probable of the sediment sources for loess in the Delaware River Valley.

The geochemistry and mineralogy of Delaware River outwash gravels have a mixed signature of multiple source lithologies. For instance, the Lake Champlain-Hudson River lobe passed across sandstone and shale lithologies in eastern Pennsylvania (Braun, 2004) and southern New York (Berg, 1980) as well as igneous (granite) and metamorphic (gneiss) rocks in the Piedmont and Highlands in New Jersey (Wolfe, 1977). Consistent with our understanding of glacial movements in the region, Ridge et al. (1992) described Late Wisconsinan-aged outwash, south of the glacial front and along the Delaware River at Brainards, New Jersey, to be dominantly (> 55%) comprised of nearby dolostone and lesser amounts of sandstone, siltstone, shale, and igneous and metamorphic rocks.

Based on lithologies of contributing meltwater deposits in the Susquehanna and Delaware River systems, we hypothesize that loess associated with each river system has a unique geochemical and mineralogical signature, which in part can be linked to the sediment source area's contributing lithology. A loess textural, geochemical, or mineralogical fingerprint common to both river systems, or unique to either could be used to trace the extent of loess additions beyond currently mapped thick deposits of the state's major river systems. In this study we examine two pedons representative of extensive loess deposits associated with the Susquehanna and Delaware Rivers to i) identify potential common characteristics of loess in this area of the eastern United States and ii) identify potential signatures of loess unique to these river systems.

2. Materials and methods

2.1. Study pedons

Two pedons (193 km apart) were chosen for analysis that are representative of regionally-extensive soils formed in a loess parent material. Soils were sampled and described following USDA-NRCS methods (Soil Science Division Staff, 2017) and field colors described

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