SILTY-SAND LOESS IN THE LEE OF DUNES

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Abstract

Thousands of small sand dunes occur on the former floor of Glacial Lake Algonquin in Michigan's Upper Peninsula, in the Great Lakes region of the USA. This glacial lake drained at ca. 11,500 cal. years ago, exposing broad, sandy flats that today are large, forested swamps. Dunes within these forests are currently stable. Although the academic community is somewhat equivocal as to the timing and formation of these dunes, most research places their age between 11,000 and 6,000 years ago, i.e., most are Holocene landforms that formed when the climate was slightly drier and warmer, but nonetheless the landscape was forested. Where these dunes abut low bedrock uplands that occur on the lake plain, they have accreted into large dune complexes. Downwind of these complexes, on the uplands, soils are mantled with ≈50 cm of sediment that is rich in fine sands and coarse silts; we interpret this sediment as coarse-textured loess. Spatio-textural data indicate that in the immediately lee of the dunes, this loess is rich in very fine and fine sands. Sand contents in the loess decrease downwind, as silt contents increase. Eventually, beyond about 1-2 km from the dunes, this sediment is silty enough that it resembles more "traditional" loess. Loess textural patterns and dune configurations clearly indicate that most eolian transport was by northwesterly winds. Our data suggest that the sands and coarse silts downwind of the dunes were primarily derived from the sandy lake plain. There, strong northwesterly winds would have promoted saltation, which helped deflate finer sediment and ultimately form large, silt-rich suspension clouds. Because the bedrock uplands are underlain by fine-textured sediment, they may have been more densely forested at this time, forming effective dust traps. We suggest that on the sand-rich lake plain, the forest vegetation was likely less dense, allowing for intermittent dune movement. As indicated from pollen data, the paleoclimate at this time was considerably drier than at present, facilitating the episodic eolian activity on the lake plain.

Our data support previous work which has suggested that eolian activity occurred here, despite the forested conditions, and that this activity was facilitated by periodic drought. This study provides an important link between dune eolian systems and more traditional, silt-rich, loess depositional systems.

Study Area

Our study area is located in the central Upper Peninsula of Michigan, USA (Fig. 1), where the sandy plain of former Glacial Lake Algonquin is covered in thousands of small sand dunes. This lake spanned much of the Upper Peninsula of Michigan from ca. 13.0 to 11.5 ka. On the lake plain, the crests of the dunes share a preferred orientation, indicative of NW winds during their formation. Bedrock uplands in the study area limit the movement of these dunes, leading to the formation of large dunes banked up against their northwestern margins. Downwind of large dunes, the uplands are variously covered with a thin mantle of sandy-silty sediment, which we interpret as loess (Figs. 2, 3).

Research Purpose

1. To better understand the paleoenvironmental conditions that led to dune formation and loess generation on this vegetated, Holocene-aged landscape
2. To investigate - spatially - the textures of dune sands and the associated downwind loess
3. To use spatial properties of these eolian sediments to understand past eolian processes in this landscape

Methods

- Sampled 15 individual, small dunes on the lake plain, as well as obtaining multiple samples from the crests of four large dune complexes
- Sampled the thin eolian sediment downwind of large dunes; most samples were within 500 m of the dunes, but we also sampled farther downwind. Sediment thickness was also recorded.
- Samples analyzed on a Malvern laser particle size analyzer
- Data analyzed and mapped using R, Grapher, ArcMap, and Excel

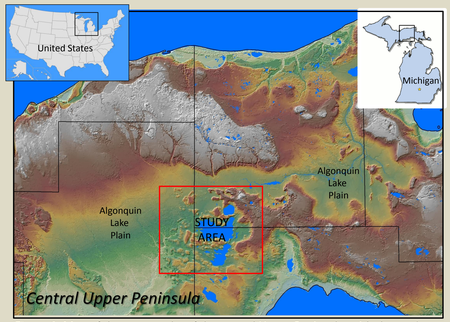

Figure 1. Map of the topography of the central Upper Peninsula, with the study area outlined in red

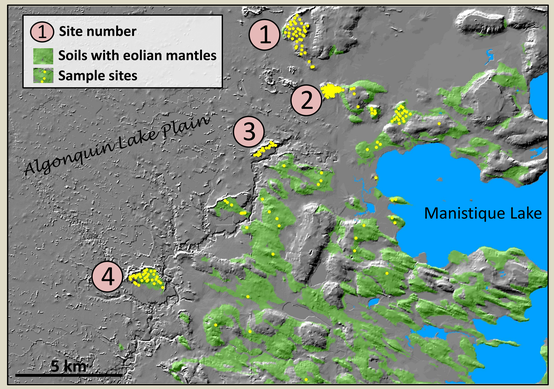

Figure 2. Map of our four main study sites. Colored polygons represent upland soils that we interpret as having a fine-textured eolian mantle. This mantle is likely also present in the lowlands, but was not mapped in these locations by the soil scientists. Details of sample locations near the large sand dunes are shown in Figure 3.

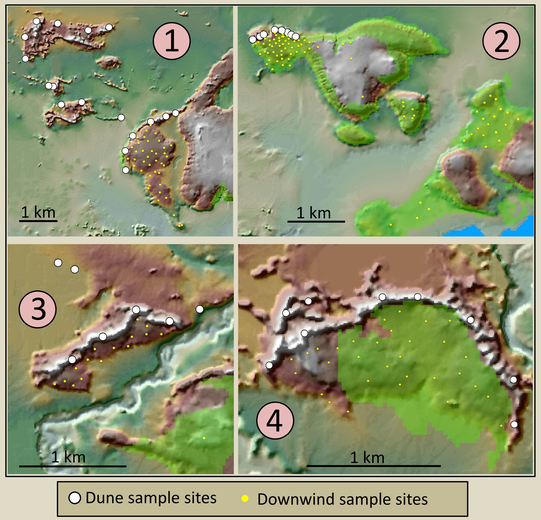

Figure 3. Details of our sample locations at and near our four main study sites. Each site includes a large dune and the finer-textured eolian sediment downwind. Note that we also sampled some of the smaller dunes, present on the lake plain proper.

RESULTS and DISCUSSION

Prevailing winds

- Many dunes on the lake plain are parabolic in form; their orientations suggest that they formed on northwesterly winds.
- Distribution of fine-textured eolian sediment across the landscape supports this interpretation; it thins to the southeast and is typically found only southeast of dunes and upland barriers.

Sand dunes

- The textures of sands within the dunes on the lake plain fine to the southeast (Figs. 4, 5). Dunes exhibited decreasing mean weighted particle size (MWPS), decreasing contents of coarse and medium sand, and increasing contents of fine and medium sand, with increasing distance to the southeast.
- We attribute this pattern to (1) strong northwesterly winds, coupled with (2) trapping of larger sands by forest vegetation, which pollen data indicate was present on at least some of the lake plain at this time.

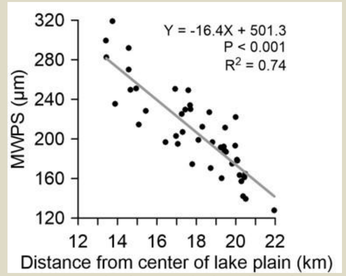

Figure 4. Scatterplot of mean weighted particle size of dune sands as a function of distance

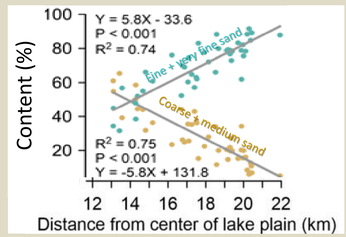

Figure 5. Scatterplot of various sand fractions in the dunes as a function of distance

Loess and fine-textured eolian sediments… farther downwind

- Many upland areas downwind of the lake plain, and often to the southeast of large dunes, are mapped in soil series that have a thin eolian mantle (Fig. 2) that averages 54 cm in thickness (Fig. 2). Beneath this mantle is either lake clay or a gravelly sediment we interpret as an erosional lag.
- The eolian sediment is dominated by fine and very fine sands in the immediate lee of the dunes, but gets increasingly silty downwind. Lehmkuhl et al. (2014) described the former type of eolian sediment (<50% silt+clay) as "silty sand."
- Downwind fining of this sediment is typified by decreasing amounts of sand, and by increasing amounts of silt, relative to sand (even fine sands) (Fig. 6).
- We interpret this sediment as loess. Beyond ≈1 km from the dunes, it is very silty and resembles traditional "thin" loess deposits.
- Our sites and data provide a short-distance example of a sand sheet to loess transition, as discussed by Pye (1995), but in a *humid* climate setting (Fig. 7).

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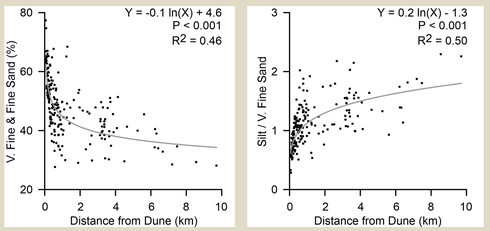

Figure 6. Scatterplots showing two examples of eolian sediment textural variation downwind of the dunes, which form the coarse, upper end-member of the dune sand-loess sequence

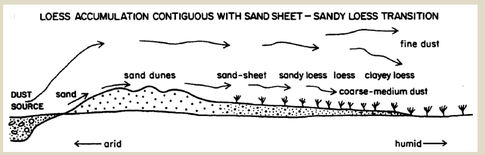

Figure 7. Schematic model of the eolian sand to loess transition in an arid-to-humid climate setting. After Pye (1995)

Conclusions

Strong winds from the west-northwest would have been necessary to deflate silt and very fine sands from the, at least partially forested, lake plain. Many of the larger sands were then accreted into dunes at the escarpment margins of bedrock uplands, while silts and very fine sands were transported over the dunes - probably in a type of low atmosphere, short-term suspension dust cloud - and into the upland forest. Here, they were trapped by vegetation. The result is an eolian mantle of silty-sand to silt texture. This work highlights the sorting effects of winds, even over short distances, and provides data on eolian facies between "pure" dune sand and "pure" loess.

References

Lehmkuhl, F., Schulte, P., Zhao, H., Hülle, D., Protze, J., and G. Stauch. 2014. Timing and spatial distribution of loess and loess-like sediments in the mountain areas of the northeastern Tibetan Plateau. Catena 117:23-33.

Pye, K. 1995. The nature, origin and accumulation of loess. Quat. Sci. Reviews 14:653-667.