EVIDENCE FOR LOESS IN NORTHWEST LOWER MICHIGAN: CHARACTERIZING THE SILTY MANTLE ON THE BUCKLEY FLATS OUTWASH PLAIN

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Abstract: We report on a silt-rich mantle, generally 35–45 cm thick, on a section of the Outer Port Huron outwash plain in northwest Lower Michigan, known locally as the Buckley Flats. Below the mantle (cap) are coarse, sandy outwash sediments. The study examines various hypotheses on the origin of the silt-rich sediment. The silty cap was sampled at 67 sites across the Buckley Flats; data derived from these sites were kriged to create smoothed surfaces of cap thickness and various textural attributes. The silty cap thins progressively from south to north, away from the Manistee River valley. The cap also becomes progressively siltier and finer-textured, and contents of medium and coarser sands diminish, toward the north, away from the presumed source. We suggest that, during the latter phases of the Port Huron advance, while the Manistee River was carrying glacial meltwater, the Buckley Flats would have been a high, dry, stable landscape, relatively near to the river. Silty sediment probably was transported by wind, out of the Manistee floodplain, just as it was with larger meltwater rivers in the Midwest, and deposited on nearby uplands. Eolian sediment deposited on the Buckley Flats, however, was more likely to have been preserved than was sediment on nearby, less stable landscapes, or on landscapes much farther away. Thus, we conclude that the silty mantle on the Buckley Flats is loess, making our study the first to document and characterize an extensive loess sheet in Lower Michigan. [Key words: loess, outwash plain, glaciation, eolian processes Port Huron moraine, Michigan.]

INTRODUCTION

For decades, the soils near Buckley, Michigan have been considered anomalies. Unlike the dry sandy soils that dominate most of northern Lower Michigan, the soils on the "Buckley Flats"—a particularly high and flat section of a Late Wisconsinan outwash plain—are silty, with sand and gravel present only at depth (Weber et al., 1958; Buchanan, 1985). The silty surface textures, coupled with the low slopes in this particular area, have fostered the development of cash grain agriculture—even here in the "cold north" (Fig. 1).

Physical Geography, 2008, **29**, 2, pp. 140-157.
 DOI: 10.2747/0272-3646.29.2.140

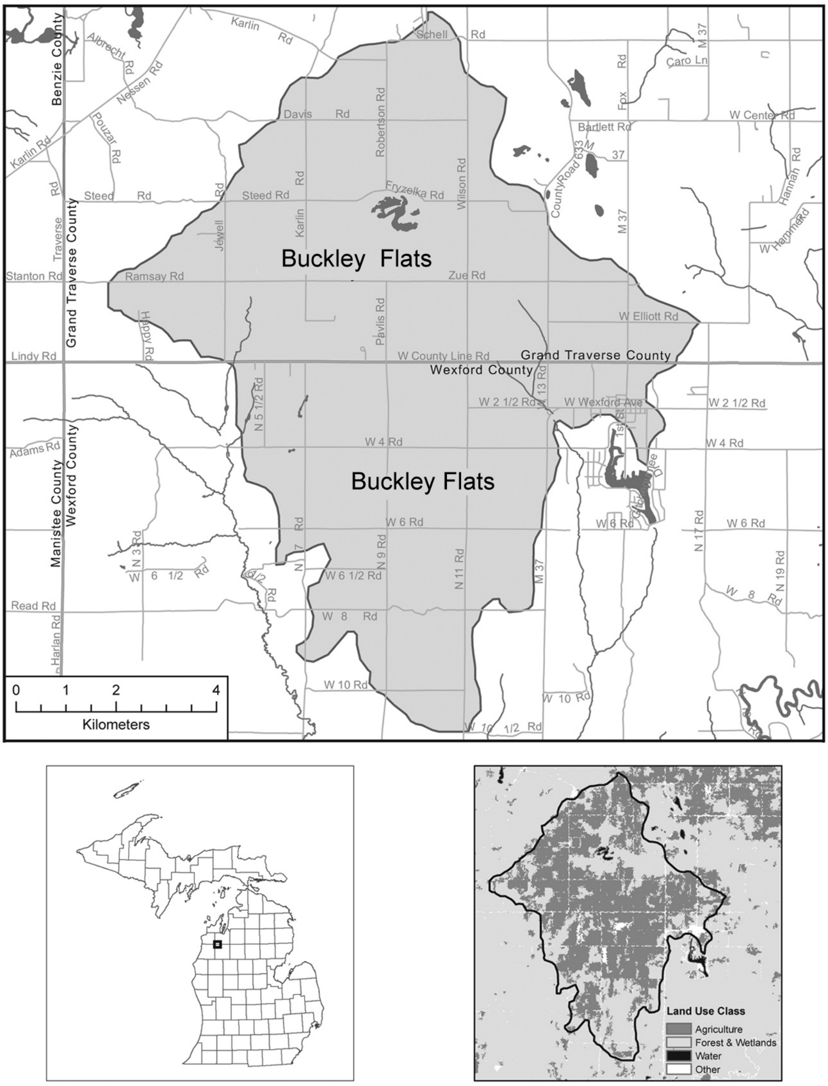

Fig. 1. The Buckley Flats and surrounding areas. Note the strong preponderance for agriculture on the Flats proper, due to the silty soils that dominate there. The sandy soils in surrounding areas are generally in forest.

Geomorphologically, the Buckley Flats are part of the Outer Port Huron morainic system, which in this part of Michigan is simply a series of broad, flat, outwash fans with steep ice-proximal slopes (Blewett, 1991; Blewett and Winters, 1995). The "moraine" itself, at the northern edge of the Buckley Flats, is little more than the steep, partially collapsed, ice-proximal slope of these outwash fans (Fig. 2). Therefore, the Buckley Flats are simply the highest (and flattest) part of the massive, areally extensive, Outer Port Huron outwash fan. They are perched high above the

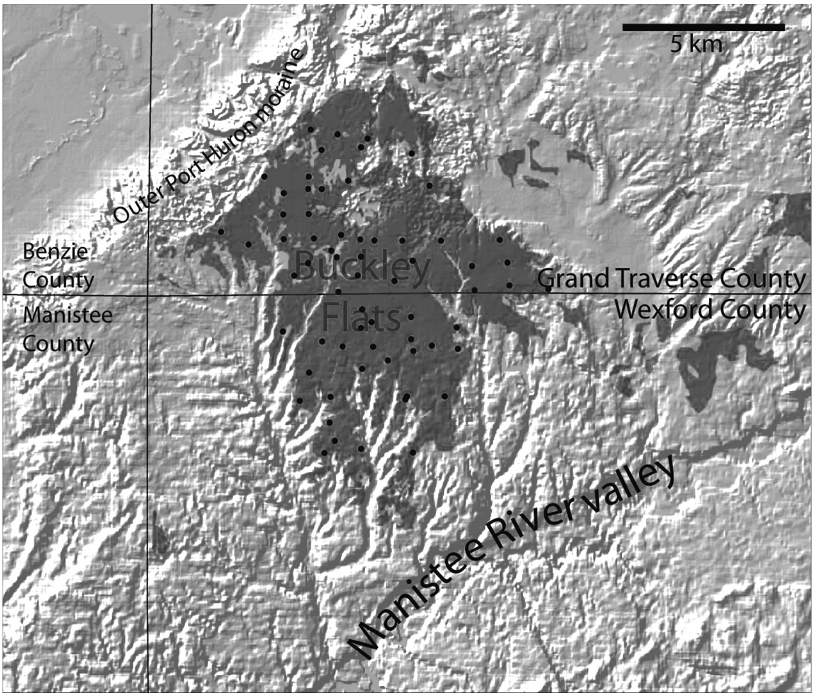

Fig. 2. Digital Elevation Model (DEM) of the study area, showing the Buckley Flats section of the Outer Port Huron outwash plain, as well as the Manistee River Valley. Areas shaded are mapped in the county soil surveys as having either Karlin or Coventry soils, both of which have, for the purposes of this research, silt caps. Sampled locations are shown as black dots.

Manistee River to the south, which carried the Port Huron meltwater (tortuously) westward to ancestral Lake Michigan.

The purpose of our research was to characterize this silty "cap" across the Buckley Flats and use these data to ascertain its geological/geomorphic origins. We hypothesized that it was either: (1) a silty lacustrine sediment, formed as the Manistee River was dammed and backed-up onto the Flats; (2) the last of a series of fining-upward outwash facies; or (3) a silty eolian sediment (loess). In this paper, we evaluate each of these hypotheses in turn.

STUDY AREA

The Great Lakes region has been repeatedly glaciated during the Pleistocene Epoch (Farrand and Eschman, 1974; Eschman, 1985; Larson and Schaetzl, 2001; Krist and Lusch, 2004). Therefore, the terrain of northern Michigan owes most of its characteristics to glacigenic processes, particularly those operative since about 18,000 calendar years ago (radiocarbon dates in this paper that derive from the literature have been converted to calendar years using the correction curve of Fairbanks et al., 2005, on this website:http://radiocarbon.ldeo.columbia.edu/

Fig. 3. Image of the Buckley Flats, looking northward from the high, interlobate uplands to their immediate south. The low area in the middle-ground is the Manistee River valley. The "perched" nature of the Buckley Flats is particularly evident in this image. *Source:* Photo by RJS.

research/radcarbcal.htm). This general period of deglaciation was interrupted several times, however, by glacial readvances. The study area (i.e., the Buckley Flats) was formed directly by one such readvance—the Port Huron readvance, which dates to about 15,100 years ago. It is the largest and most areally extensive readvance in the Great Lakes region, with its main end moraine spanning from Ontario, through the Lower Peninsula of Michigan, across the bottom of Lake Michigan, into Wisconsin (Blewett, 1991; Blewett et al., 1993), although its correlative moraine in eastern Wisconsin has yet to be identified (Syverson and Colgan, 2004). In the northern Lower Peninsula of Michigan, the large and impressive Port Huron moraine is mainly composed of ice-contact stratified drift and glaciofluvial sediment that were deposited as the ice margin stagnated and melted in place (Blewett, 1991; Blewett and Winters, 1995; Schaetzl, 2001; Schaetzl et al., 2000). Thus, vast expanses of dry, sandy soils, with occasional kettles, stretch out for kilometers in front of the moraine (Schaetzl et al., 2006). In the northwestern Lower Peninsula, the Port Huron margin takes on a slightly different character than elsewhere; here it is marked by the presence of two large moraine crests with a wide, sandy outwash plain between, attributed to a second readvance shortly after the first, main one. The earlier (outermost) of the two advances is responsible for the Outer Port Huron moraine, whereas the later advance formed the Inner Port Huron moraine (Blewett, 1991). Both advances, however, were of similar character—characterized by widespread ice-marginal stagnation and the formation of high, sandy, morphosequence-like outwash fans—and have broad outwash plains distal to them.

The Buckley Flats are a particularly high and flat section of the Outer Port Huron outwash plain that lies "perched" between the former ice margin and a large area of high interlobate uplands several km to the SE (Figs. 2 and 3). Between the

Buckley Flats and this interlobate upland exists the southwesterly flowing Manistee River, which carried Port Huron meltwater, eventually emptying into an early version of Lake Michigan. Several high terraces can be found in the valley, indicating the degree to which the valley was filled by thick deposits of outwash, prior to Holocene entrenchment and incision. Deep, dry gullies, fluvially integrated with the Manistee valley, have developed on the southern, distal margins of the Buckley Flats (Fig. 4A).

The Buckley Flats can be defined topographically as the high, largely ungullied massif of the Outer Port Huron outwash fan. As such, they cover roughly 90 km^2, spanning 12 km in a N–S direction and 10 km E–W. The Flats slope very gently to the southeast at approximately 3–3.5 m/km, and are exceptionally flat and unkettled in their central section (Fig. 4B). Elevations along the northern margin, proximal to the ice-contact slope, are between 340 and 345 m above sea level. This area is slightly more rolling, due largely to occasional kettles (Fig. 4C). At the southern margin but north of the area of extensive gullying, elevations of 326 m are typical, but these sites are still perched 80 m above the Manistee valley, which lies only about seven km to the south (Fig. 3).

With the exception of the bottoms of incised fluvial channels and in the few scattered kettles that dot the landscape, the Buckley Flats are mantled with a silt-rich, sandy loam cap of ~35–45 cm in thickness. The cap contains a significant amount of silt and very fine sand, much more than does the outwash sediment below. Where the cap is thin, long-term cultivation has caused sand from below to be mixed into the cap, and coarser than normal textures result. Irrigation is common on many of the fields in the flatter parts of the Buckley Flats (Fig. 4B).

The silt and fine sand-dominated soils of the Buckley Flats are atypical for the region. Most upland soils in the region are sandy, reflecting the nature of the sandy glacial drift; silty sediments and soils are actually quite rare (Whiteside et al., 1968; Mokma and Vance, 1989; Rindfleisch and Schaetzl, 2001; Schaetzl, 2002; Schaetzl and Weisenborn, 2004; Schaetzl et al., 2006). On the northern half of the Buckley Flats, in Grand Traverse County, the silty soils are mapped within the Coventry (coarse-loamy over sandy or sandy-skeletal, mixed, frigid Alfic Haplorthods) and Karlin (sandy, mixed, frigid Entic Haplorthods) series. In the southern half of the Flats, in Wexford County, these same soils are mapped only within the Karlin series. The reason for the naming disparity stems from the age of the two soil surveys; Grand Traverse County was mapped nearly 30 years previously, and series nomenclature and definitions had changed in the interim. Both soil series represent similar soils and parent materials; there is no noticeable change at the county line. Where gullies have incised into the main level of the outwash plain (Fig. 4A), the silty cap is absent. Here, soils formed solely in the outwash sands and gravel, such as Kalkaska and Rubicon (both sandy, mixed, frigid Haplorthods), are mapped. Most soils on the dry Buckley Flats are well or moderately well drained.

METHOD

We first created a map of the silty soils on the Buckley Flats—the Karlin and Coventry series—in a GIS. Then, we colored these map units, made them partially

Fig. 4. Images of land use and topography on the Buckley Flats. All photos by RJS. (A) Deep gully, typical of the southern, distal section, near the Manistee River. (B) Looking south on a large, irrigated field typical of the central section. Such fields are usually planted to corn, soybeans, or wheat. The interlobate area to the south of the Buckley Flats is visible in this image. (C) Kettles and swales typify the rolling fields and expanses common on the ice-proximal, northern end of the Buckley Flats.

transparent, and draped the map over a hillshaded DEM, in order to develop a working field map for sampling purposes. Our goal was to sample across the expanse of silty soils of the Buckley Flats, in a rough grid-like pattern (as modified by landowner permissions) with no more than 1 or 2 km between most sample points. In some of the northern, kettled parts of the Flats (Fig. 4C), areas mapped in the soil survey as having a silt cap had, in actuality, been so modified by cultivation that they were deemed not acceptable for sampling. After obtaining permission and verifying that we were on an acceptable soil map unit, we sampled the silty cap with a bucket auger. In all, 67 sites were sampled across the Flats. At each site, we also verified, by augering further, that the substrate was sandy outwash. Cap samples of 100–500 g were taken well above the lithologic discontinuity to the sand and gravel outwash below. Although the cap is quite thin in places, we believe that the samples we obtained are good representations of silty cap material, with as little in-mixed sand and gravel from below as possible.

The samples were air dried and lightly ground in a ceramic mortar, with a wooden pestle, and passed through a 2 mm sieve. The remaining fine-earth portion was then passed through a sample splitter and recombined (four passes total) to maximize intra-sample homogeneity. When necessary, organic matter was removed using dilute H_2O_2. Particle size analysis was done on chemically dispersed, 2-g samples (in a water-based solution with $[NaPO_3]_{13}{\cdot}Na_2O$ as the dispersant, after shaking for two hours), on a Malvern Mastersizer 2000E laser particle-size analyzer. Mean grain size and clay-free particle-size data were generated within the Malvern and Microsoft Excel software packages, respectively. Data were imported into a GIS and standard kriging and contouring analyses (Oliver and Webster, 1990; Matejicek et al., 2006) performed on the cap textural data, as raw textural data and on a clayfree basis.

RESULTS AND DISCUSSION

General Characterization of the Silt Cap Sediment

The silt cap on the Buckley Flats is typically about 35–45 cm thick (39.2 cm mean; 10 cm minimum, 89 cm maximum), above gravelly sand and coarse sand outwash. The lithologic discontinuity between the cap and the outwash below is typically gradational over a 10–20 cm thick layer, but can often be abrupt. The outwash sediment below the cap is commonly sand or gravelly sand in texture, with almost no silt or clay. Short-distance variation in the texture of the outwash is, however, very high, as is typical for this type of sediment.

The cap samples average 25.1% (maximum 47.0%) silt, and 27.0% silt when calculated on a clay-free basis. The cap samples average 7.3% clay, with most falling within the coarse clay (0.2–2.0 µm) fraction. The mean contents of the five major sand fractions are: very fine sand (50–125 µm), 5.7%; fine sand (125–250 µm), 9.3%; medium sand (250–500 µm), 29.8%; coarse sand (500–1000 µm), 18.9%; and very coarse sand (1000–2000 µm), 0.9%. The distinct bimodality of the particle size distributions of the cap samples, as exemplified by the typical samples shown in Figure 5, almost certainly resulted from the admixture of the silty

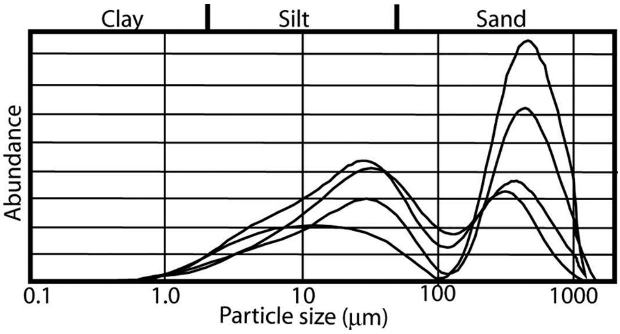

Fig. 5. Continuous particle size distribution curves for four representative samples of the silt cap. Note the distinct bimodality.

sediment in the cap with the coarser sands below, by various forms of pedoturbation. The data in Figure 5 suggest that the original cap sediment was originally much siltier and less sandy than at present. Particle-size distribution within the silt (2–50 μm) fraction is relatively uniform—that is, the mean contents of the very fine, fine, medium, and coarse silt fractions (6.2, 9.2, 4.9, and 4.8%, respectively) are relatively similar. Most commonly, the cap is sandy loam in texture (Soil Survey Division Staff, 1993). At many sites, however, it has a loamy coarse sand or coarse sandy loam texture.

The cap is uniformly present across the flattest parts of the Buckley Flats, but thins on sloping surfaces and is entirely absent within gullies and on slopes greater than about 15% (Figs. 2 and 4A). We attribute this distribution to deposition on stable sections of the Buckley Flats immediately after meltwater had stopped flowing across it, followed by erosion of the cap on the more sloping surfaces (Rebertus et al. 1989; Schaetzl, 2008). No evidence of silty cap material exists in the bottoms of through-flowing gullies and channels.

Spatial Variation in the Cap Attributes: Hypothesis Testing

We used the default kriging subroutine in ArcGIS to create maps of various cap attributes (Figs. 6–11). These maps and data will be used to test and evaluate three different hypotheses as to the genetic origin of the silty cap on the Buckley Flats, not unlike that done by West and Rutledge (1987). Geomorphologically, there are essentially only three possible formative mechanisms for the formation of a silty cap on an upland landscape like the Buckley Flats. We present and explore these three hypotheses below.

> *Hypothesis 1: Silty lacustrine sediment associated with a lake, formed by a glacially impounded Manistee River.* It is relatively straightforward to postulate a Port Huron–age ice dam on the southwestward-flowing Manistee River, with impounded water behind it (Fig. 12). This dam

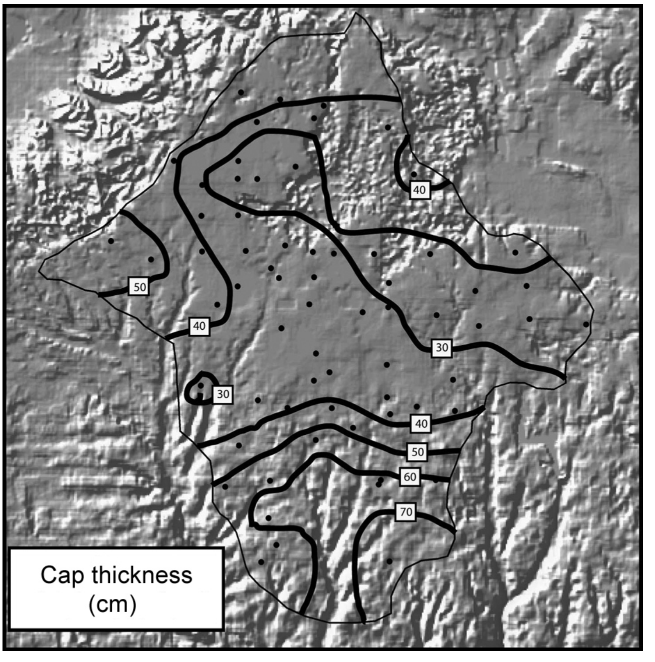

Fig. 6. Kriged, isoline map of the thickness of the silt cap across the Buckley Flats, set on a DEM base. In this and subsequent maps, the outline of the Buckley Flats that is used has been derived from maps of the extent of Karlin and Coventry soils, as well as interpretation of topographic constraints (flat, upland areas), and sampled locations are shown as black dots.

would have occurred several kilometers to the south of the Buckley Flats, where the river intersects the Outer Port Huron moraine.

Our data do not support this hypothesis for the origin of the silt of the Buckley Flats, regardless of the water height that is postulated for such a lake, for several reasons. The Buckley Flats form one of the highest landscapes south of the Port Huron margin, and thus would have been flooded the least amount of time, and under the shallowest of waters, if at all. More importantly, many possible outlets exist to the south and east of the study area that would have drained such a lake far below the elevation of the Buckley Flats. Regardless, even if one can envision the Flats as being flooded, and postulate that the Buckley silts are lacustrine, similar materials would then have to be present in many other areas south and east of the Port Huron moraine, and to our knowledge they are not.

Hypothesis 2: Silty outwash facies. This hypothesis presupposes that the last vestiges of meltwater from the Port Huron ice sheet may have been rich in silt, and deposited a silty facies above the sandy and gravelly strata below.

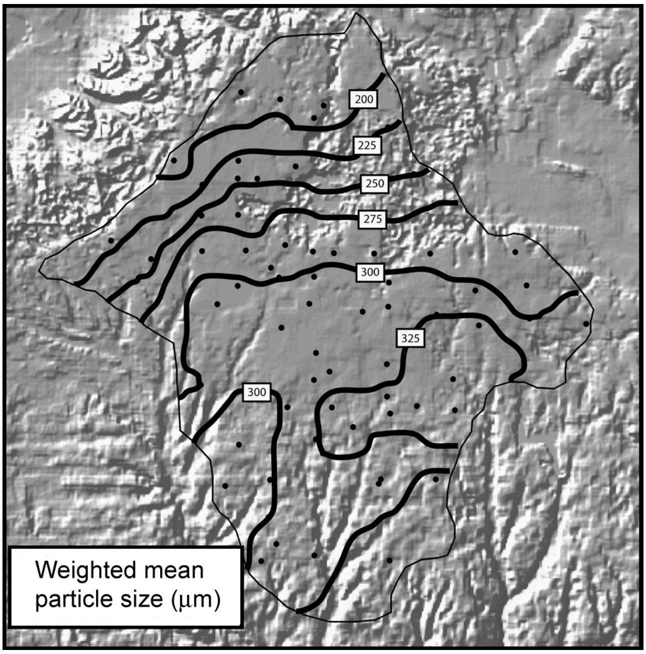

Fig. 7. Kriged, isoline map of weighted mean particle size of the cap across the Buckley Flats, set on a DEM base.

This hypothesis is, however, not supported by the textural data, which show that the silt cap coarsens with distance from the ice front (Fig. 7). Subaerial, fluvial outwash facies would likely exhibit a fining trend with distance from the source, i.e., the moraine front. Similar counterarguments could be made regarding thickness (Fig. 6). Lastly, the mantling sediment shows no signs of stratification, which might have suggested a glaciofluvial origin.

> *Hypothesis 3: Loess, with the Manistee River valley outwash as its main source*. Loess exhibits strong and predictable spatial trends in particle size and thickness (Smith, 1942; Fehrenbacher et al., 1965; Smalley, 1966; Olson and Ruhe, 1979; Ruhe, 1984; West and Rutledge, 1987; Pye, 1995). Thus, the maps in Figures 6–11 can be used to provide insight into this hypothesis.

Loess deposits tend to be thickest near their source, thinning progressively and systematically downwind (Wascher et al., 1947; Frazee et al., 1970; Rutledge et al., 1985; Fehrenbacher et al., 1986; Leigh, 1994; Pye, 1995; Muhs and Bettis, 2000). Thus, clear spatial patterns in thickness should be evident if the silt cap is loess. The thickness of the silt cap on the Buckley Flats displays clear, predictable thinning tendencies from south to north (Fig. 6). The cap exceeds 60–70 cm in thickness in the southern Flats, despite the gullied nature of this part of the landscape and the

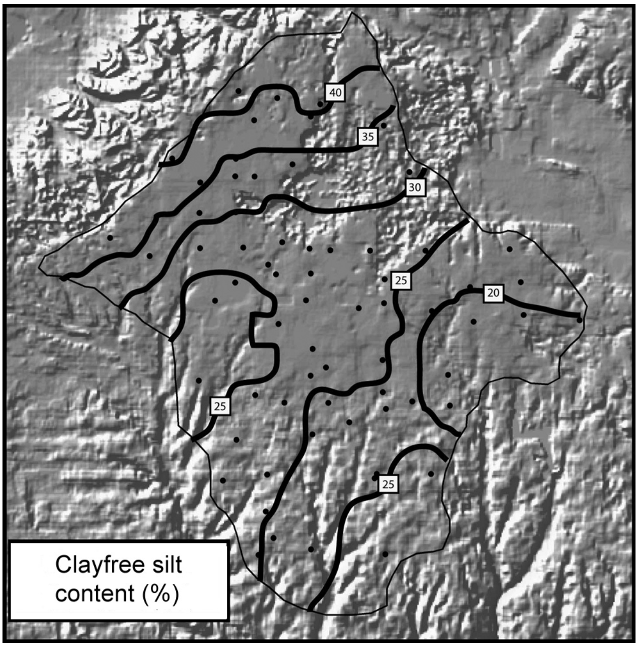

Fig. 8. Kriged, isoline map of clayfree silt content of the cap across the Buckley Flats, set on a DEM base.

evidence for postglacial erosion. In the north-central sections of the Flats where the landscape is flattest, 6 km to the north, the cap is only half as thick: 25–35 cm. This spatial trend suggests that the silty mantle sediment is loess, and that its source lies to the south of the Flats. Slight increases in thickness in the northwest and northeast sections of the Flats may reflect a secondary loess source in these areas, such as the outwash plain/valley train that lies proximal to (north of) the Port Huron moraine. Alternatively, these apparent thick areas may simply be statistical artifacts. Regardless, the cap clearly does have a strong thinning trend to the north, as would be expected for loess coming from a southerly source such as the Manistee River floodplain.

Loess deposits also tend to be coarsest near their source areas and become progressively more finely textured farther downwind as larger particles get deposited nearer to the source (Ruhe, 1954; Rutledge et al., 1985). On the Buckley Flats, based on weighted mean particle size data, the silt cap is coarsest in the southeast corner, coinciding with the thickest mantle (Figs. 6 and 7). Here, the mean particle size exceeds 325 um, which falls in the medium sand range. In the far north, only 12 km away, the weighted mean particle size of the cap sediment is <200 μm, within the fine sand range. The greater coarseness of the cap in the southern part of the Flats cannot be ascribed to increasing amounts of pedoturbation of sand from below, as the cap is thicker here than in areas to the north. Thus, we believe that this spatial trend reflects the original sedimentological characteristics of the cap. The

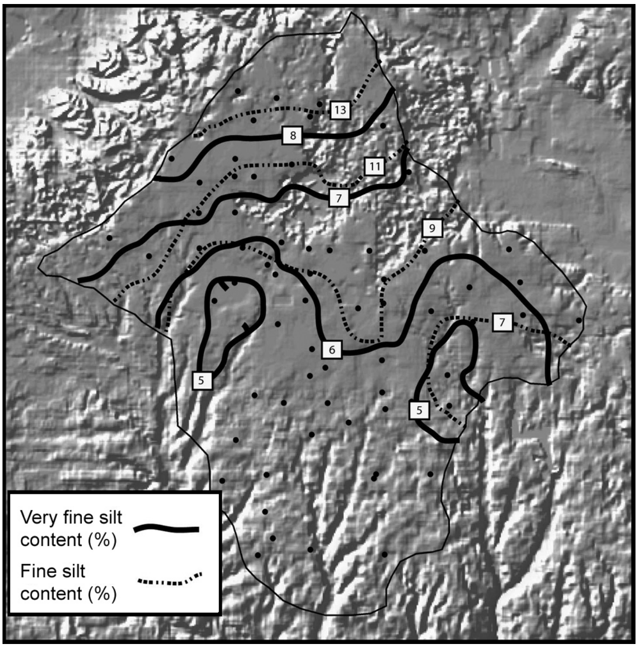

Fig. 9. Kriged, isoline map of very fine (2–12 μm) and fine (12–25 μm) silt contents of the cap across the Buckley Flats, set on a DEM base.

data in Figures 7–11 also discount the notion (first suggested by Fig. 6) of any secondary loess sources to the north of the Flats; the cap in the two areas that exhibited secondary thickness maxima in Figure 6 remains fine textured and does not get coarser, as it would if these areas were near to a secondary source area.

Contents of several particle-size fractions were determined on clayfree bases, the latter being used to negate any effects of clay translocation (Rutledge et al., 1975; Ruhe, 1984; Schaetzl and Anderson, 2005). Clayfree silt content (Fig. 8) shows a systematic increase from south to north across the Flats, again indicative of a southerly source and an eolian origin.

We next chose to focus on the contents of some of the silt fractions, for these size fractions are most likely eolian and could not have been admixed into the cap from below, as could some of the sand fractions. The very fine and fine silt fractions in the cap are typically less than 13% each, and thus their amounts are minimally affected when converted to a clayfree basis. Thus, we report total amounts of very fine and fine silt (Fig. 9). These particle size fractions can be easily carried in suspension by even slight winds, and are common in loess, especially far from the presumed sources (Ruhe, 1954; West et al., 1980). Both very fine and fine silt contents increase to the north, across the Flats, indicative of an eolian origin with a southern source. This trend mirrors that of clayfree very fine sand (Fig. 10), a particle size fraction that is capable of being carried by strong winds and which reaches high values in the northwest part of the Flats.

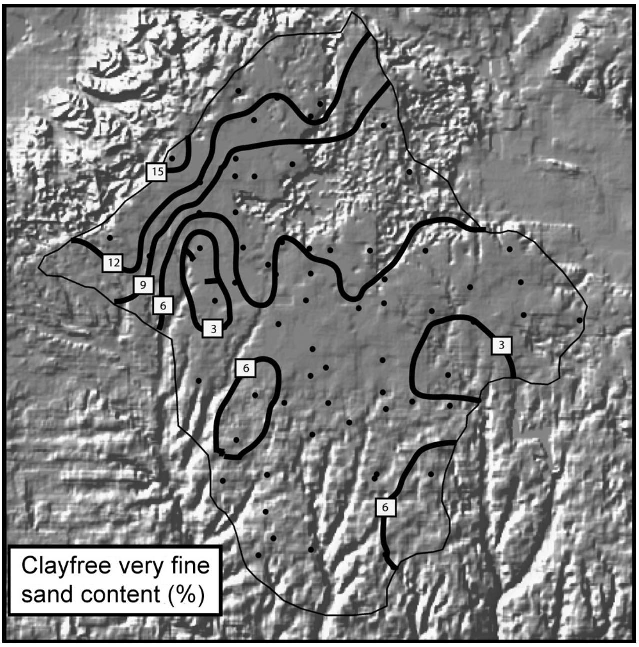

Fig. 10. Kriged, isoline map of clayfree very fine sand content of the cap across the Buckley Flats, set on a DEM base.

Lastly, we examined some of the coarser sand fractions, which presumably could have been transported by wind, but not for great distances and perhaps only by saltation. If the cap is eolian, these fractions should be most common near the source area. Clayfree medium sand contents epitomize the coarser sand fractions, and are found most abundantly in the southern and southeastern parts of the Flats (Fig. 11). Large amounts of medium and coarser sand contents occur in loess only near the source area, which in this case is presumably the Manistee River.

We, therefore, conclude that the silty materials that mantle the Buckley Flats outwash surface have all the characteristics of a thin loess sheet, with a Manistee River valley source area (Fig. 12). Like all loess deposits associated with glacial meltwater valleys, the mantle here thins, progressively and predictably, away from the valley, and along these same trend lines the loess sediment becomes finer textured and siltier. Although the arguments that can be made for the silt cap as being a loess deposit are clear and convincing, supportive arguments and logic go beyond the spatio-textural data discussed above; they make sense geomorphologically as well. Recall that the Manistee River carried all of the Port Huron meltwater for the western half of Lower Michigan; the Au Sable River carried the eastward-flowing meltwater. Given the immense size of the Port Huron moraine and outwash surface (Blewett, 1991; Schaetzl et al., 2006), it seems logical to assume that the Port Huron meltwater event was large and long-lasting, perhaps continuing for many decades (Blewett et al., 1993). During this time, the Manistee River valley would have been

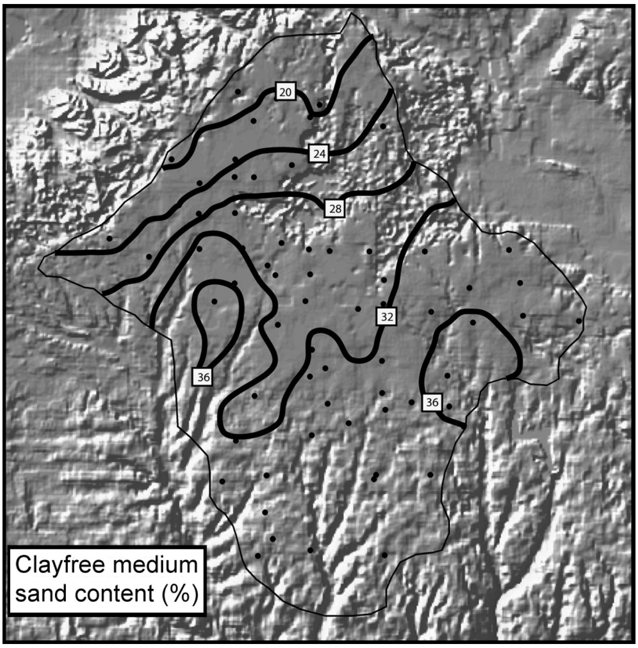

Fig. 11. Kriged, isoline map of clayfree medium sand content of the cap across the Buckley Flats, set on a DEM base.

full and choked with meltwater in summers, and in winter, dry and available as a silt and fine sand source. Thus, like most large meltwater valleys in the upper Midwest, it is a loess source that must be, on first principles, examined seriously, and our data support it as the logical, but heretofore unrecognized, loess source.

Implications and Significance of the Buckley Flats Loess Cap

As we have discovered on other upper Midwest landscapes (Schaetzl and Loope, 2008; Schaetzl, 2008), late-glacial loess, regardless of its production rates and source locations, is seldom found as continuous sheets on landscapes that are unstable (e.g., those cored with ice, riven with permafrost, steeply sloping, or being overrun with meltwater). This is also true on the Buckley Flats; the kettled northern edge of the Flats has a very thin and spatially erratic cap. Likewise, loess is absent in many of even the smallest gullies on the Flats.

Loess in the upper Midwest seems to be thickest and preserved today only on landscapes that were topographically high, geomorphically stable, and subaerially exposed during the (however long) loess-production period (Schaetzl, 2008). In this part of northwest Lower Michigan, the highest part of the Port Huron outwash plain is, literally, the Buckley Flats, and thus it may have been free of meltwater *early* during the Port Huron event, as meltwater found lower paths to the Manistee River (Fig. 12). Given the data presented in Figures 6–11, it seems likely that loess was coming

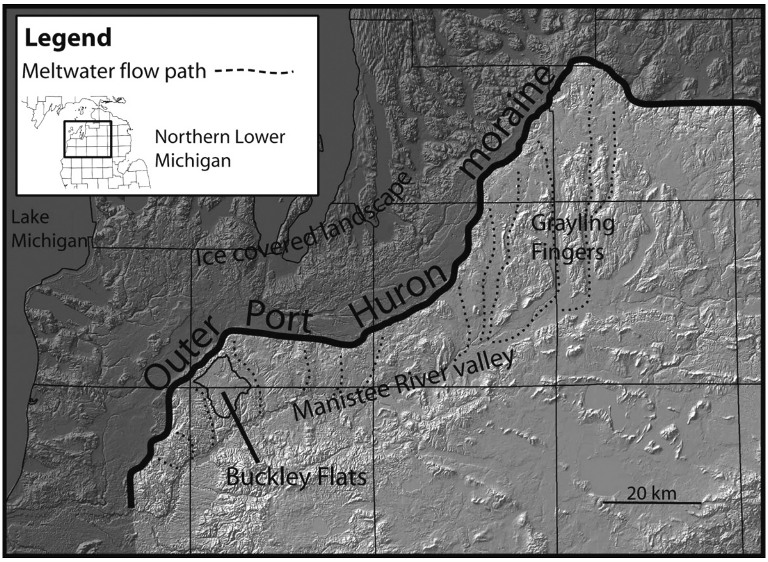

Fig. 12. Regional DEM image of northwest Lower Michigan, showing the landscape as it may have looked at the time of the Outer Port Huron advance, and its major meltwater paths.

from the Manistee Valley, but was only able to persist on the flat, high, and stable parts of the Buckley Flats. The Flats also had the advantage of being relatively close to the source area. Many sites within the Grayling Fingers (Fig. 12), two counties to the east, also have a silty cap on their uppermost, flattest surfaces (Schaetzl and Weisenborn 2004; Schaetzl, 2008); this landscape lies a few km from the Port Huron outwash plain.

The importance of our study, therefore, rests on these two findings: (1) relatively small meltwater valleys are capable of producing significant amounts of sediment that can be readily identified as loess; and (2) loess on rapidly deglaciating landscapes is likely to be preserved only on the highest, most stable parts of the landscape. Lastly we note that, although other work has documented disjunct loess deposits in Michigan (Schaetzl, 2008; Schaetzl and Loope, 2008), our work is the first to document and characterize a continuous loess sheet in the state.

CONCLUSION

The cap that covers much of the Buckley Flats is a silt-dominated, eolian sediment (loess) that has the Manistee River floodplain, which lies immediately south of the study area, as its main source area. Despite the limited spatial extent and thinness of the cap deposit, several of its properties, when examined spatially, clearly point to an eolian origin: (1) it thins progressively from south to north; (2) it gets progressively siltier and finer textured along the same axes; and (3) contents of medium and coarser sands diminish markedly toward the north, away from the presumed source. We suggest that, during the latter phases of the Port Huron advance, while the Manistee River was still carrying glacial meltwater, the Buckley Flats would have been a dry, stable, upland landscape, relatively near to the river. Any eolian sediment that reached the Flats was much more likely to be preserved than on nearby, less stable landscapes, or on stable landscapes much farther away. Thus, our study is the first to document and characterize a small but significant and continuous loess sheet in Lower Michigan.

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