CHARACTERIZING, MAPPING, AND INTERPRETING THIN LOESS DEPOSITS IN THE WESTERN UPPER PENINSULA OF MICHIGAN

By

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ABSTRACT

CHARACTERIZING, MAPPING, AND INTERPRETING THIN LOESS DEPOSITS IN THE WESTERN UPPER PENINSULA OF MICHIGAN

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This research examines the distribution, thickness and textural characteristics of thin, patchy, loess deposits in the western Upper Peninsula of Michigan. Although local soil surveys have documented loess in Baraga, Marquette and Iron Counties, at the northeastern margins of the North American, midcontinent loess region, this thesis is the first detailed study of these loess deposits. Within the study area, loess is ~ 30-60 cm thick and is usually underlain by sandy glacial deposits. Where the loess deposits are thin, it appears that pedoturbation processes have likely mixed some of the lower, sandy materials into the loess. For this reason, most of the loess has a bimodal continuous textural curve, with a primary modal particle-size within the 25-75 µm fraction (the loess) and a secondary mode in the 250-500 µm fraction (the in-mixed sand). These loess deposits were likely sourced from both distant and local areas, including ground moraines, outwash plains, and the floodplains of small meltwater streams. Within the Peshekee Loess region, I have identified four loess sections, each of which has unique characteristics that set it apart from the whole: the Amasa, Covington, Republic, and Champion sections. This research (1) recognizes multiple source areas for loess, (2) develops and interprets textural data on the thin Peshekee Loess, and (3) documents the effects of mixing within these loess deposits. This research is the first to document both the extent and textural characteristics of loess deposits situated at the extreme margins of much larger and thicker, regional-scale, loess region.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. Introduction

Loess, wind-blown silt, is found across vast parts of China, Central Asia, Europe, New Zealand, Alaska, and on both the Great Plains and Central Lowlands of North America (Smalley 1975; Mason et al. 1999; Bettis et al. 2003; Roberts et al. 2003). In North America, there are five distinct areas of thick, extensive loess deposits: (1) Alaska, (2) eastern Washington and the adjacent uplands in Oregon (3) Idaho, (4) the Great Plains, and (5) the Central lowlands. At small scales, loesses of the Great Plains (Nebraska, Kansas, and Colorado) and Central Lowlands (Missouri, Iowa, Illinois, Indiana, and areas to the north and south) appear to be a continuous sheet, however at large scales it is apparent that these loess bodies have very different thickness trends and origins, and are interrupted by areas where loess is absent (Muhs and Bettis 2003). Loess in these areas tends to be associated with glacial episodes and provides a critical record of environmental change during and after the last glacial phase in North America (Muhs and Bettis 2003). Interpretation of this record of environmental change requires accurately linking stratigraphic sequences (and deposits) of loess to their source areas, along with understanding the spatial characteristics of the loess itself (Mason et al. 1999; Muhs and Bettis 2000; 2003; Schaetzl and Hook 2008; Scull and Schaetzl 2011).

Loess deposits, regardless of origin, require three conditions in order to form: (1) a persistent sediment source, (mainly silt size and fine sand particles, that are loose, usually on an unvegetated surface, and able to be deflated), (2) a sustained/suitable wind direction and wind velocity, and (3) a site for sediment accumulation (Pye 1995). Loess deposits tend to be thickest near their source and become progressively thinner downwind, providing evidence of paleowind directions (Wascher et al. 1947; Frazee et al. 1970; Rutledge et al. 1985; Fehrenbacher et al. 1986; Leigh 1994; Pye 1995 Schaetzl and Hook 2008, Stanley and Schaetzl 2011). In the Midwestern United States, loess can exceed 30 meters in thickness (Smith, 1942; Olson and

Ruhe 1979; Fehrenbacher et al. 1986), but generally become thinner to the east and northeast, from the Mississippi River valley, until, by Michigan they may only be as thin as 30 cm, and often are thinner or absent (Scull and Schaetzl 2011). Relatively thin loess deposits blanketing much of the Great Lakes region have, until recently, largely been ignored (e.g. Schaetzl 2008; Schaetzl and Hook 2008, Schaetzl and loope 2008; Hobbs et al. 2011; Scull and Schaetzl 2011; Stanley and Schaetzl 2011). Often, these thinner and smaller loess deposits do not have an obvious source because they do not lie adjacent to broad meltwater river valleys (e.g., the Mississippi and Missouri River valleys) that, in the Midwest, have traditionally been assumed to be the main sources for loess. On the contrary, loess deposits in Michigan have mainly been linked to nontraditional loess source areas, like outwash plains, moraines, lacustrine plains, and mid-size glacial meltwater valleys (Schaetzl 2008; Schaetzl and Hook 2008; Schaetzl and Loope 2008; Hobbs et al. 2011; Stanley and Schaetzl 2011; Scull and Schaetzl 2011).

The Natural Resource Conservation Service (NRCS) county-level soil surveys identify a number of soils within Michigan's western Upper Peninsula that have formed in "modified eolian material and underlying loamy and sandy glacial drift" (Berndt 1988; Linsemier 1989; Schwenner 2007). Most researchers that have worked in this area have concluded that this thin, "mantling" material is, indeed, loess (Flint 1971; Berndt 1988; Linsemier 1989; Schwenner 2007). To that end, Scull and Schaetzl (2011) identified (at small-scale) multiple loess areas or "sheets" throughout Wisconsin and Michigan's western Upper Peninsula (WUP). Within the WUP, Scull and Schaetzl (2011) identified, from east to west, the Peshekee, Iron County, Marenisco-Winegar, and Keweenaw loess sheets.

The focus of this thesis research mainly centers on the Peshekee Loess, located in Baraga, Iron, and Marquette Counties. This landscape is extremely heterogeneous, with hummocky, high-relief (averaging > ~30 m), Precambrian bedrock-controlled uplands, and interspersed glacial meltwater streams and valleys. Until ~11 500 cal. yrs BP, the northern parts of the area were occupied by the Laurentide Ice Sheet (LIS). Outwash plains, end moraines, ground moraines, and midsize glacial meltwater valleys formed at this time, and are common and often in close proximity to one another. Glacial drift is relatively thin (< 30 m) and patchy in most areas – and nonexistent on many bedrock uplands. On this recently deglaciated landscape, the NRCS has mapped many hectares of two-storied soils that have formed in thin (avg. ~ 40-60 cm), silty, eolian material and underlying loamy and sandy glacial till on high-relief bedrock uplands. The research goals of this thesis are to characterize the thickness and textural attributes of the Peshekee Loess, and to determine the likely source area(s) for this loess.

Mapping the textural and thickness character of the Peshekee Loess is vital to a determination of the region's loess source(s). These data will also provide evidence on the post-glacial environment (e.g. paleowind directions and wind velocities) during loess transport in the western Upper Peninsula of Michigan. Moreover, the loess here is at the far eastern edge of the vast North American loess, and thus, data from it will provide a unique perspective on thin loess at the margins large loess areas. Information about the margins of a deposit like the Peshekee Loess can provide valuable insights about its formation, perhaps more than data from the core, or central, parts of the deposit. Therefore, this research will contribute to (1) a complete mapping of North America's loess and (2) advancing our knowledge of the paleoenvironmental conditions while the LIS was retreating from the Great Lakes region.

2. Literature Review

Smalley and Smalley (1983) defined loess in terms of process and considered four mechanisms related to its formation: (1) silty sediments between 20-60 µm forms, (2) the material is transported by wind, (3) the sediment is deposited, and (4) the deposit experiences post-depositional changes. In broad terms, Pye (1995) defined loess as sediment composed predominantly of silt-size particles (20-60 µm), formed by the accumulation of wind-blown dust. Loess deposits are common in the high latitudes of the world where continental and alpine glaciers have historically developed (Flint 1971). Glaciers are known for grinding clastic sediment into sand and silt sized particles. Loess maps worldwide show that wind-blown silt covers a significant amount of the Earth's land surface, perhaps as much as 10 percent (Pecsi 1963; Muhs and Bettis 2003). Eolian deposits, specifically loess, provide evidence of environmental change during the Quaternary period, and thus, have been the focus of much sedimentological and paleoenvironmental study (Mason et al. 1999; Muhs and Bettis 2000). In this literature review, I will (1) discuss the background and significance of loess, (2) describe the mechanical and physical characteristics of loess, and (3) describe research on the loess deposits in Michigan, USA.

2.1 Background and Significance

North America has some of the thickest deposits of *last-glacial* loess in the world (Roberts et al. 2003). In the Midwestern United States, loess deposits are mapped adjacent to broad glacial meltwater valleys and are thickest near their source meltwater valley (e.g., Mississippi, Missouri, Illinois and Wabash Rivers) where loess exceeds ~ 30 meters in thickness (Smith 1942; Olson and Ruhe 1979; Fehrenbacher et al. 1986; Muhs and Bettis 2000; Mason 2001; Bettis et al. 2003). Here, loess deposits not only tend to be thickest near major meltwater valleys, but also texturally coarsest (Smith 1942; Frazee 1970; Bettis et al. 2003; Roberts et al.

2003). The systematic thinning and fining of loess, downwind from its source area, provide evidence of both source area and paleowind directions (Wascher et al. 1947; Frazee et al. 1970; Rutledge et al. 1985; Fehrenbacher et al. 1986; Leigh 1994; Pye 1995). These data can later be used to test atmospheric general circulation models (Muhs and Bettis 2000). Moreover, loess can record periods of landscape stability (soil development) and instability (loess accumulation) in periglacial environments (Follmer 1996; Bettis et al. 2003; Hobbs et al. 2011; Schaetzl 2008)

2.2 Loess Production

Mechanisms for the production of naturally occurring silt-size material include: (1) release of existing silt-size material from parent rocks, (2) glacial grinding, (3) frost weathering, (4) eolian abrasion, (5) salt weathering, (6) chemical weathering, (7) clay pellet aggregation and (8) biological processes (Pye 1995). In the mid-latitudes, silt is commonly produced by continental glaciers in a process that Smalley (1990) defines as glacial grinding. Loess research in central North America has been dominated by a conceptual model linking loess deposits to large rivers that carried meltwater and glacially ground sediment, often from the LIS. The model describes glacial meltwater valleys choked with silt-rich discharge in the summer, which later become dry (low flow) and unprotected in the winter (and during low-flow periods in summer); strong prevailing winds are then capable of blowing dry silt out of the river valley and onto the adjoining uplands (Frye et al. 1962; Smalley 1966, 1975; Ruhe 1983; Johnson and Follmer 1989; Follmer 1996).

2.3 Loess Transportation and Deposition

Transport of eolian sediment can occur by (1) suspension, (2) saltation and/or (3) creep - in all cases transport depends on the size of the particle and wind characteristics. Eolian sediment is not only transported as single grains, but also as aggregates of silt and clay (Mason et al. 2003). Suspension within the atmosphere can take place with coarse silts or grains < 50 µm and as long as the particle's minimum threshold velocity and/or turbulence is obtained (Tsoar and Pye 1987). Saltation usually takes place with fine and medium sand (125-500 μm) grains (Tsoar and Pye 1987). Grains between these particle ranges (50-125 μm) can be transported by short-term suspension or modified saltation, depending on the wind velocity or turbulence (Tsoar and Pye 1987).

Loess deposition occurs as a result of (1) a decrease in wind velocity or (2) particles being washed out of the atmosphere (via precipitation). In any case, deposition is facilitated by surface roughness and/or vegetation, as a result of decreases in wind velocity or turbulence. (Tsoar and Pye 1987; Mason et al. 1999). Loess is initially deposited rather uniformly across an area, covering the landscape evenly, with the thickest depths and coarsest sediment recorded near the source (Ruhe 1954; Frazee et al. 1970; Fehrenbacher et al. 1986). However, the spatial relationships between the loess source and associated deposits depend largely on the nature of the relief, climatic and vegetation gradients in an area (Tsoar and Pye 1987; Pye 1995; Mason et al. 1999). For example, loess deposits adjacent to and downwind from broad river valleys exhibit a classic wedge-shape, where particles traveling close to the ground are eventually trapped by vegetation and/or a topographic barrier proximal to the source, while the finer particles traveling higher in the atmosphere are deposited further downwind (Pye 1995).

2.4 Preservation

Loess is initially deposited uniformly across a landscape, regardless of position along a catena (Schaetzl and Anderson 2005). However loess preservation is greatly affected by the topography of the underlying surface and the geography of the source area. Ruhe (1954) showed that, due to post depositional processes, loess is least sorted when it overlies summit landscape positions, and is better sorted on slopes where slopewash processes have sorted the loess with the regolith. Furthermore, where the land surface topography follows an irregular relief pattern, post-depositional processes can cause loess landscapes to be highly dissected. Loess deposits in a dissected landscape tend to be best preserved and thickest on uplands (Ruhe 1954), whereas loess on side slopes tends to be thinner, better sorted, and coarser, due to erosion and sorting of fine grained sediments (Ruhe 1954). Furthermore, foot and toeslope positions tend to have thicker loess deposits, in comparison to uplands that have loess, and are composed of even finer sediment (Ruhe 1954). As a result of post depositional processes, colluvial additions can easily be incorporated into loess deposits and lead to an overestimation of (1) loess thicknesses and (2) percentage of fine-earth fraction, especially on foot and toeslopes (Smalley 1972; Pye 1995). In sum, flat uplands are ideal sampling site locations when characterizing a loess deposit because they tend to be the most stable landscape position, and thus would be the most representative location for a loess deposit (Ruhe 1954).

2.5 Spatial Characteristics of Loess Deposits

Eolian particles fall out of suspension according to Stokes Law (Pye 1995), thus, larger particles fall out of suspension more quickly than small particles. Because of this sorting, loess deposits often exhibit a systematic fining of particle size with increasing distance from the source (Smith 1942; Ruhe 1954; Frazee et al. 1970; Olson and Ruhe 1979; Muhs and Bettis 2000). Very fine sand, as well as coarse and very coarse silt contents often decrease with increased distance from a source, whereas the amount of fine silt and clay increases with distance downwind (Ruhe 1954; Frazee et al. 1970; Olson and Ruhe 1979). As a result, the textural character of a loess deposit can, and often is, mathematically predictable downwind from its source area(s) (Smith 1942; Ruhe 1954; Fehrenbacher et al. 1965; Ruhe 1969; Frazee et al. 1970; Muhs and Bettis 2000).

Particle size distributions and the thickness of loess deposits vary greatly, based on the characteristics of the region’s vegetation and topography and the distance from the source, along the dominant wind direction. Tsoar and Pye (1987) showed how the wedge-shape of a loess deposit is greatly affected by the landscape surface roughness and the type of vegetation present during deposition. Forests are more efficient in trapping dust than steppe or tundra vegetation due to its greater roughness (Tsoar and Pye 1987). A large change in surface roughness leads to a rapid increase in net deposition closer to the roughness boundary. For example, at the edge of a forest where a large change in surface roughness is present, loess is easily trapped by the tall vegetation (and washed to the surface) creating a steep gradient loess wedge (Tsoar and Pye 1987; Pye 1995). Conversely, where the height of the vegetation is lower (e.g., grass land or tundra), suspended particles are less likely to be trapped, resulting in a more gradually sloping loess wedge (Tsoar and Pye 1987).

Mason et al. (1999) expanded on the surface roughness model developed by Tsoar and Pye (1987) and suggested that not only do vegetation and topographic barriers facilitate loess deposition, but these factors also provide a barrier between thick and thin loess deposits. Mason et al. (1999) argued that loess distribution in the Central Lowlands of North America often reflects regional topographic controls on the transport of sand from eolian sediment sources, and in turn controls the distribution of thick loess. In thier model, long-term accumulation of loess occurs mainly downwind of topographic obstacles that limit eolian transport of sand, and associated re-entrainment dust. This process begins as sand from the source area saltates along the source surface and, in the process, stirs up silt and clay sized particles. The deflated, fine particles are then re-entrained and carried further downwind. This process continues until the sand grains encounter a barrier, e.g., a steep valley, an escarpment, or an increase in local relief. Because of the barrier, saltating sands become trapped and the windward surface of the barrier eventually becomes stabile, while the surface downwind of the barrier continues to accumulate fine sediments and is, therefore, unstable. In this model, topographic barriers often act as a boundary between thick and thin loess deposits.

Additionally, Putman et al. (1988; 1989) suggested that loess is both thicker and coarser near *wider* valley sections, and ultimately correlates to the amount of sediment available and the dominant wind direction.

2.6 Loess Chronology in North America

The loess and intercalated paleosols in the mid-continental United States have been extensively studied during the past century and serve as a key stratigraphic foundation in deciphering the Pleistocene history of North America (Ruhe 1983; Follmer 1996; Muhs and Bettis 2000; Forman and Pierson 2002). The ages of loess deposits found within North America are usually based on the dates obtained from (1) radiocarbon dating of soil organic material (either underlying and/or overlying the deposit), and/or (2) optically stimulated luminescence (or thermoluminescence) dating of the loess itself. The loess deposits found on the Great Plains and Central Lowlands of North America are generally correlated based on the age of the deposit. The following section will include a brief discussion on the nomenclature and chronology of the major loess units found in central North America.

There are up to seven major loess deposits in the Mississippi and Missouri River basins (Follmer 1996). Three of the most recent, and most extensive, of these loess deposits are the Loveland Loess, the Roxana Silt and the Peoria Loess (Willman and Frye 1970; Ruhe 1983). The Loveland Loess is the oldest unit known in North America and is identified throughout the upper Midwest in the Missouri, Arkansas, Mississippi, and Ohio River basins (Ruhe 1969; Willman and Frye 1970; Ruhe and Olson 1980; Rutledge et al. 1996; Follmer 1996). Based on thermoluminescence ages, Loveland Loess was first deposited ~ 165,000 cal. yr BP. Deposition ended ~ 110,000 cal. yr BP, confirming its Illinoian age (Forman et al. 1992). The Sangamon

Geosol subsequently formed in the Loveland Loess (Follmer 1996; Ruhe 1956) during slow or nondepositional periods, between ~ 130,000 and ~ 60,000 cal. yr BP, which represents the last interglaciation (Leigh and Knox 1993, 1994; Markewich et al. 1998). Within the middle Mississippi Valley, usually overlying the Loveland Formation (i.e., the Sangamon Geosol developed in Loveland Loess) is Roxana Silt (loess) - a middle-Wisconsin aged deposit (Johnson and Follmer 1989; Leigh and Knox 1993). Thermoluminescence ages on the Roxana Silt range from ~ 30,000 to ~ 53,000 cal. yr BP for sites in the middle Mississippi Valley (Forman et al. 1992; Rodbell et al. 1997; Markewich et al. 1998). Ages of the Roxana Silt vary based on location along the Mississippi River Valley and by different dating methods. The Farmdale Geosol developed in the upper part of the Roxana Silt, at sites in and near the Mississippi River Valley (Follmer 1983). Thermoluminescence ages in the Farmdale Geosol range from ~30,000 to ~ 23,000 cal. yr BP (Forman et al. 1992). Loess in a similar stratigraphic position as the Roxana Formation (i.e., the Formdale Geosol developed in Roxana Silt) is recognized in Iowa as the Pisgah Formation and in eastern Nebraska and Kansas as the Gilman Canyon Formation (Forman et al. 1992; Mason et al. 2007). However, these correlative units generally have younger ages; ranging between ~ 30,000 and ~ 45,000 cal. yr BP (Leigh and Knox 1993; Follmer 1996; Maat and Johnson 1996).

The youngest and thickest loess unit east of the Missouri River is the Peoria Loess (Bettis et al. 2003). In many localities within the Midwest and Central Lowlands Peoria Loess accumulated on top of the Roxana Silt and the Farmdale Geosol. At Loveland, Missouri, Peoria Loess is as much as 41 m thick (Forman et al. 1992). In the upper and middle Mississippi Valley, deposition of Peoria Loess began ~ 30,000 cal. yr BP and ended ~ 12,900 cal. yr BP (Leigh and Knox 1993; Markewich et al. 1998; Grimley 2000; Forman and Pierson 2002; Bettis et al. 2003).

The irregular loess thickness of Peoria Loess suggests that loess accumulation during this time was likely variable. For example, recently, Stanley (2008) reported on thin (between 35 and 70 cm, respectively) loess in north-central Wisconsin, and found that these loess deposits range between ~ 15,200 cal yr. BP and ~ 12,000 cal yr. BP. In north-central Lower Michigan Hobbs et al. (2011) provided evidence of episodic loess deposition during the early-Holocene. Radiocarbon ages on bulk charcoal from nine paleosols within kettle-bottom silt deposits were found to span the entire Holocene. One date is late Pleistocene in age (10,930 ^{14}C years ago) and another is from the last 1000 years (920 ^{14}C years ago). The remaining seven dates span from ~ 9,500 to ~ 5,400 ^{14}C years ago, i.e., generally between ~ 10,700 and ~ 6000 cal. years BP. Thus, Hobbs et al. (2011) and Stanley (2008) provided evidence for loess deposition in the Great Lakes region well after the LGM and into the Late Pleistocene and even well into the Early Holocene.

2.7 Loess in Michigan and nearby areas

Until recently, loess in Michigan has been largely overlooked. The state was not recognized as having major loess source areas, due to the absence of large glacial meltwater river valleys. However, lately, thin loess deposits have been recognized in areas such as northwestern Lower Michigan (Schaetzl and Hook 2008), eastern Upper Peninsula (Schaetzl and Loope 2008), north-central Lower Michigan (Schaetzl 2008), and central Lower Michigan (Hobbs et al. 2011). The loess deposits noted in Michigan are thin compared to the loess deposits studied in the Great Plains and Central Lowlands of North America. Thin loess deposits in Michigan could be attributed to (1) the recent, and in some cases rapid, retreat of the LIS from this region and (2) the mechanics of the source area(s) from which the loess deposit’s originated.

Schaetzl and Hook (2008) reported on soils with 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. The silty cap thins progressively from south to north, away from the

Manistee River valley, and also becomes finer in surface texture toward the north. The authors concluded that the silt-textured mantle on the Buckley Flats is loess, thereby documenting loess in Lower Michigan. The presumed source for this loess is the Manistee River valley, which is thought to have carried glacial meltwater from the Port Huron Advance. This model suggests that Port Huron meltwaters, choked with silty sediment, later deposited these materials on the Manistee River floodplain, from which, these fluvial deposits were deflated and transported by wind and, over time, deposited on the nearby uplands.

Schaetzl and Loope (2008) examined the distribution of a thin, silty deposit on uplands in eastern Upper Peninsula of Michigan. The authors explored the distribution, likely source, and general nature of this 20-60 cm-thick silt cap, using the loess formation model of Mason et al. (1999). Textural, geochemical, and mineralogical characteristics of the silty cap provided evidence that the uplands are mantled by loess which deflated from dried-up lake floors after nearby post-glacial lakes had drained.

Stanley and Schaetzl (2011) concluded that a thin loess deposit in north-central Wisconsin had two loess sources, neither of which fell within the traditional mode of "glacial meltwater valley." The eastern margins of the north-central Wisconsin loess deposit has a thin (< 35 cm thick) silt loam surface texture, and this eolian cap thickens (to > 70 cm) and coarsens towards the west and northwest, such that, on its western margins, the loess mantle is dominated by very fine and fine sands. Collectively, data on loess particle size distributions, thickness, and silt mineralogy suggest that this loess had sources in two distinct and disjunct landscapes: (1) the late Wisconsin terminal moraine to the northwest, and (2) the sandstone-dominated landscapes to the west and southwest. Stanley and Schaetzl (2011) suggested that post-glacial thawing of the permafrost-affected landscape probably led to draining of ice-walled lake plains on and behind the moraine, located just northwest of the loess, as well as destabilization of slopes in the sandstone landscapes to the south and southwest of the loess; in both cases, large quantities of sediment were exposed for deflation. The study made two significant contributions to eolian research: (1) it suggested that loess deposits can have two distinctly different and disjunct loess sources, and (2) landscapes other than the traditional "glacial meltwater valley" can serve as loess sources.

Schaetzl (2008) focused on a silty cap overlying till and outwash in the Graying Fingers region of northern Lower Michigan. Data there suggested that the loess was derived from two local-source areas, the Port Huron outwash plain and (to a lesser extent) the Manistee River valley. Schaetzl (2008) found that the silty cap is geochemically and texturally unlike the glacial sediments that underlie it. Also, loess is only located on the flattest parts of the Finger uplands and within the bottoms of upland dry kettles. Because of post depositional erosion, loess was only preserved on flat upland surfaces or within closed depressions. The Graying Fingers work suggests that outwash plains and medium-size meltwater streams can also be significant sources for loess (Schaetzl, 2008).

Hobbs et al. (2011) reported on small bodies of silty sediment, frequently occurring in the bottom centers of dry kettles. The anomalous silty sediment is found in an otherwise dry and sandy interlobate region of central Lower Michigan, known as the Evart Upland. The small silty deposits are dominated by fine silts, and often have one or more charcoal-rich paleosols within their sedimentary sequence. Secondary particle size peaks of medium sand in these deposits match the sands found on the kettle backslopes. Moreover, the backslope sediments contain little silt, and what silt they have was typically coarse silt, suggesting that the silt in the kettles was not derived solely from the kettle backslopes. The authors suggest that the silt is loess that was intermittently blown onto the landscape from the nearby Muskegon River floodplain and/or from other, silt-rich surfaces recently disturbed by fire. Charcoal fragments within the paleosols provided evidence for Holocene-age loess deposition in central Lower Michigan.

Michigan's loess deposits, although rare, have mainly been linked to last-glacial outwash plains, mid-size meltwater river valleys and abandoned lake floors. Additional loess research in Michigan could potently provide more evidence in support of glacigenic landforms as loess source areas, e.g., glacial outwash plains, mid-size glacial meltwater stream valleys, dried-up lake plains, ground moraines, and end moraines. Additionally, expanded loess research in Michigan could contribute to mapping the total extent of North America's loess deposits.

2.8 Summary

Mapping the spatial characteristics of loess deposits is an important step to understanding the paleoenvironmental conditions that existed during loess deposition. After a loess provenance is identified, paleoenvironmental conditions during loess deposition can often be inferred, e.g., temperature, wind direction and/or wind velocity.

Loess deposits in mid-continental North America are common and are often reported adjacent to, and downwind of, large glacial meltwater river valleys. The thickest and coarsest loess deposits are found near the source whereas thinner loess deposits and finer-textured sediment is reported farther from the source. Thus, loess deposits have spatial trends with respect to thickness and particle size that enable the determination of source areas.

Recently, loess research in Michigan has suggested that glacigenic landforms rich in silt content (e.g. outwash plains, mid-size stream valleys and dried up lake floors) can also serve as significant source areas for loess. Although Michigan loess deposits are relatively thin (i.e., between ~ 20 – 60 cm) and particle size distributions are more variable, these deposits do illustrate the traditional "wedge-shaped" character of a loess deposit.

3. Study Area

The focus of this study is Peshekee Loess and the very northeastern margins of the Iron County Loess, located in Michigan's western Upper Peninsula[1] (Scull and Schaetzl 2011). Combined, both regions of loess span parts of Baraga, Dickenson, Marquette, and Iron Counties (Figure 3.1). The NRCS has recognized loess deposits in the soils in all of these counties, where it usually overlies glacial till, glacial outwash and/or bedrock (Berndt 1988; Linsemier 1989; Schwenner 2007). This chapter provides background information on the extent of the broad study area, in addition to its bedrock geology, glacial history, physiography and soils.

3.1 Extent of the Broad Study area

Loess in the western Upper Peninsula, although extremely patchy, extends across Menominee, Marquette, Dickinson, Baraga, Iron, Houghton, Keweenaw, Ontonagon, and Gogebic Counties (NRCS SSURGO Data). Due to the vast extent of the loess and the lack of road access and time, this research was limited to a ~ 560,000 hectare area that extends east-west for 80 km and north-south for 70 km (Figure 3.1). The broad study area, lies within Baraga, Dickinson, Marquette, and Iron Counties and includes the Peshekee Loess and the very northeastern parts of the Iron County Loess (Scull and Schaetzl 2011). Later in the thesis the study area is defined by the extent of the loess sample site locations.

[1] Although this is the first study to focus on the characterization of the silt mantle on soils of Baraga, Dickinson, Iron, and Marquette Counties, all of the county soil surveys for this region have identified soils formed in silty or loamy eolian deposits over sandy and gravelly outwash, till, and bedrock (Berndt 1988; Linsemier 1989; Schwenner 2007). Because, by definition, sediment with this description has been widely accepted as loess (Schaetzl and Loope 2008; Schaetzl and Hook 2008; Schaetzl 2008; Scull and Schaetzl 2010), I will refer to the silt loam mantle as loess for the remainder of this paper.

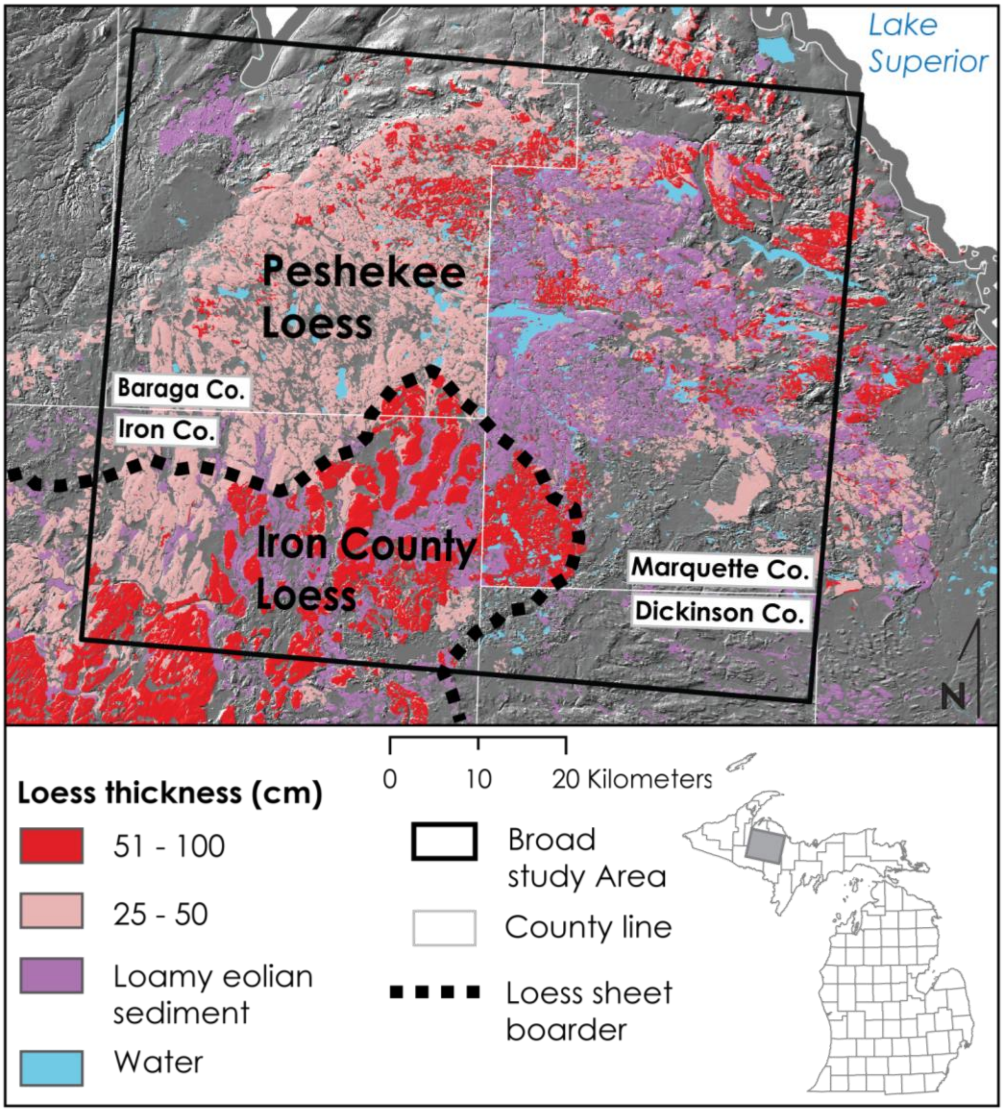


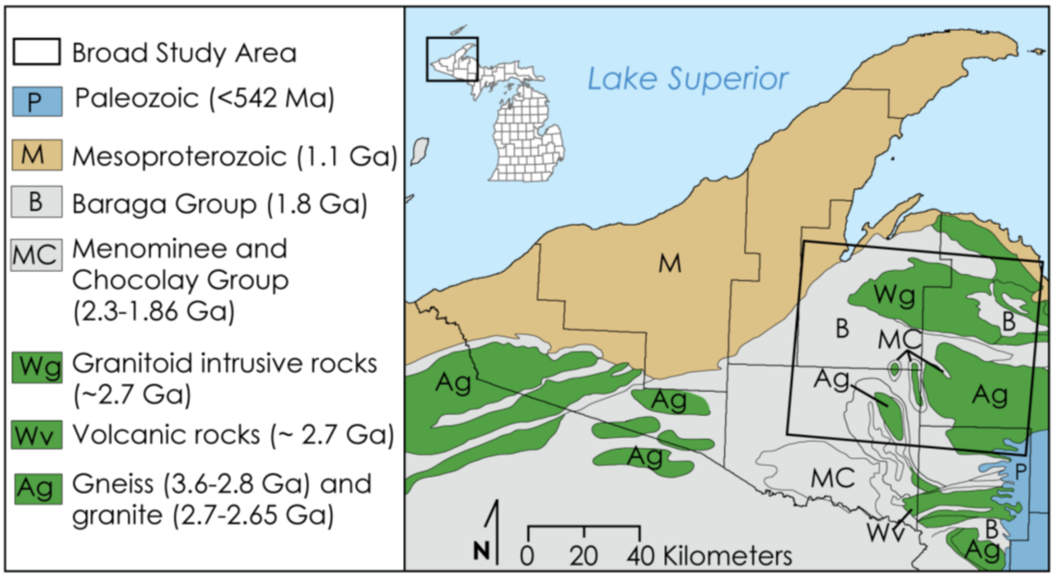
Figure 3.1: Generalized map of soils with loess parent materials in western Upper Michigan (after Berndt 1988; Linsemier 1989; Schwenner 2007). Red represents soils series mappped with loess thicknesses of 51 - 100 cm. Pink represents soil series mapped with loess thicknesses of 25 - 50 cm. Soils with loamy eolian sediment parent materials are colored purple. The broad study area outline includes parts of two loess regions named by Scull and Schaetzl (2011). For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

The broad study area is situated in the Superior Upland physiographic province. Fenneman (1938) describes the Superior Upland as part of the Canadian Shield, dominated by underlying Precambrian bedrock, mainly crystalline in structure, with some rock types completely worn down, while others are more resistant and stand up as ridges. Repeated Pleistocene glacial advances have deposited glacial drift in places, removed the mantle of many rock types in other locations, destroyed historical drainage networks, and left behind what now looks like a virgin landscape – minus the dense forests and abundant inland lakes and wetlands (Leverett 1911; Fenneman 1938). The landscape's hydrology is young, and thus streams, swamps, and lakes are abundant, forming a deranged drainage network.

3.2 Bedrock Geology

Because of only thin deposits of glacial drift in many places, the land surface topography generally mimics the underlying bedrock surface. Precambrian crystalline bedrock underlies the southern and central sections of the broad study area, whereas Paleozoic sandstone benches are exposed on the northern edge along Lake Superior (Card 1990; Wikgren 2007). The bedrock geology of this region is extremely complex, and knowledge of the geology is not at all complete (Bornhorst and Brandt 2009). Sedimentary, igneous and metamorphic rocks exposed at the surface can vary greatly over short distances, and most are obscured by glacial deposits and/or vegetation and water.

The Precambrian rocks of the broad study area are over 2.5 Ga old, and include the southern extent of the Canadian Shield (Card 1990). Some of the more extensive Precambrian rock units within the broad study area include Archean granites and gneisses, as well as Paleoproterozoic and Mesoproterozoic sedimentary rocks (Figure 3.2). The Archean granites and gneisses are not only some of the oldest rocks in Michigan, but also on Earth (Sims 1993). The Republic (granite) and Palmer (gneiss) Formations are common in the north-central part of the broad study area and are Eoarchean (4.0-3.6 Ga) to Mesoarchean (3.6-2.8 Ga) in age (Schulz and Cannon 2007; Figure 3.2). These rock types form granitic bedrock glades with steep hills, short cliffs, and talus slopes at the base of bedrock exposures. Glacial drift is generally < 6 meters thick on the uplands, with many bare bedrock outcrops; thicker glacial deposits occupy the valleys (Schwenner 2007; Wikgren 2007).



Precambrain Episode	Formal Unit Names	Dominant Rock Type
Mesoproterozoic (~1.1 Ga)	Jacobsville Sandstone Munising Formation	Basalt lava flows, Conglomerate, Sandstone, shale
Baraga Group (1.8 Ga) Menominee and Chocolay Group (2.3-1.86 Ga)	Michigamme Formation Goodrich Quartzite Negaunee Iron Formation Ajibik Quartzite Siamo Slate Hemlock Formation Badwater Greenstone	Argillite, Basalt to andesite lava flows and pyroclastic rocks, Banded iron formation, Diabase dikes and sills, Graywacke, Shale, Quartzite
Granitoid intrusive rocks (~2.7 Ga) Volcanic rocks (~ 2.7 Ga) Gneiss (3.6-2.8 Ga)and granite (2.7-2.65 Ga)	Mona Formation, Kitchi Formation, Lighthouse Point Basalt, Palmer Gniess, Republic Granite, Campeau Creek Gneiss	Basalt pillow lava flows, Andesite, Dacite, Gneiss, migmatitic gneiss, Amphibolite

Figure 3.2: Generalized bedrock map of Michigan's western Upper Peninsula and an outline of the broad study area's common rock episodes, along with examples of formal rock unite names and dominant rock types (after Sims 1993; Cannon 2007; Bornhorst and Brandt 2009).

An abrupt transition from granites and gneisses to high-grade metamorphic sedimentary rock types is evident in the central and southwestern regions of the broad study area (Figure 3.2). South of the region dominated by granites and gneisses, outcrops are less concentrated and form large, rounded ridges. Here, glacial drift is thicker (< ~ 20 meters) and parallel drainage networks are more common (as opposed to the dendritic systems common to the north). This landscape is mostly underlain by metamorphic sedimentary rocks that are Paleoproterozoic (2.3-1.76 Ga) in age; in Michigan known as the Marquette Range Supergroup. They formed as fine-grain sedimentary rock types, which later formed into shale and in some cases slate (metamorphosed shale). Rocks of the Paleoproterozoic era are particularly complex in Michigan, and are lumped into the Marquette Range Supergroup which is subdivided into the lower Chocolay Group (the oldest), the middle Menominee Group, and the upper Baraga Group. Each is separated by unconformities that represent long periods of erosion (Bornhorst and Brandt 2009; Figure 3.2).

The northwestern corner of the broad study area is underlain by a thick succession of volcanic and sedimentary rocks of Mesoproterozoic (1.76 to 1.1 Ga) age rocks that formed within the Midcontinent rift system (Davis and Green 1997) (Figure 3.2). A common Mesoproterozoic sedimentary rock found in the northeastern parts of the broad study area and along the Lake Superior shoreline is the Jacobsville Sandstone (Sims 1992; Figure 3.2). The Jacobsville Sandstone is identified by its mottled reddish-pinkish-whitish colors; it is almost pure quartzose sandstone with some minor siltstone, shale and conglomerate lithologies.

The bedrock underlying the broad study area is dominantly Precambrian igneous and high-grade metamorphic rock type. Given the resistant nature of these lithologies, it is unlikely that any of the local bedrock formations have weathered enough to form silt-rich residual soils, as described by the NRCS.

3.3 Glacial History

During the Pleistocene Epoch, the broad study area (BSA) was repeatedly covered by glacial ice (Attig et al. 1985; Lowell et al. 1999). However, overall, glacial deposits in this region are relatively thin (average < ~ 30 meters) and vary greatly in thickness (Vanlier 1963; Derouin et al. 2007). In addition to glacial till and outwash, alluvium, lacustrine and eolian deposits typically are the main forms of regolith in the region (Berndt 1988; Linsemier 1989; Schwenner 2007). In places, ice advance positions are well-marked by end moraines, but others are poorly defined due to later ice readvances, wave action, and/or collapse topography (e.g., Larson and Schaetzl 2001). Despite this lack of temporal accuracy, the glacial landforms and deposits of this region have been correlated to any of four glacial lobes, which last advanced into the area between approximately 15,000 and 11,500 cal. yrs ago[2], during the Wisconsin Glaciation (Attig et. al. 1985; Lowell et al. 1999; Larson and Schaetzl 2001; Derouin et al. 2007). The four major ice lobes that contributed to the construction of the glacial landscape, from west to east, are the Ontonagon, Keweenaw Bay, Michigamme, and Green Bay Lobes (Attig et al. 1985; Peterson 1986; Figure 3.3). This section discusses the major moraines and other glacial deposits within the broad study area and their significance to Peshekee Loess.

[2] In this thesis, all 14C age estimates taken from the literature have been converted into calendar years BP, using the calibration curve of Fairbanks et al. (2005): http://www.radiocarbon.ldeo.columbia.edu/research/radcarbcal.htm (Fairbanks et al. 2005).

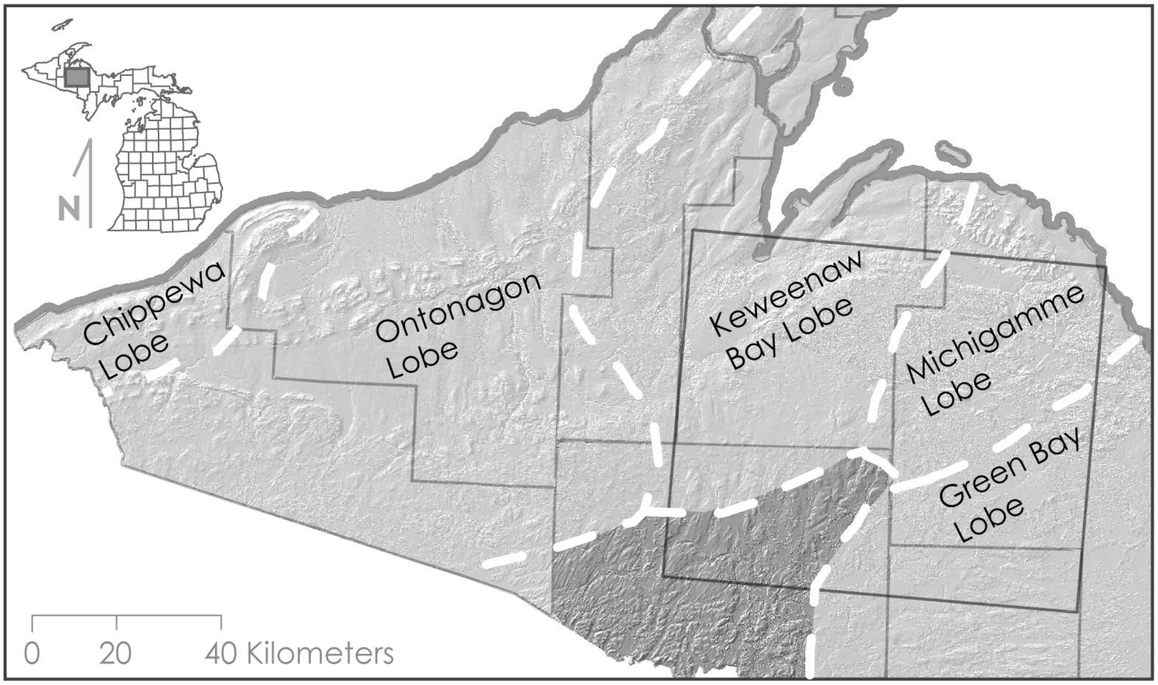


Figure 3.3: Extent of the last four major ice lobes that sculpted the glacial landscape of the broad study area (Attig et al. 1985; Peterson 1986).

The southern-most moraine within the BSA is the Winegar/Watersmeet Moraine, deposited by the Ontonagon and Keweenaw Bay Lobes (Figure 3.4). The Winegar Moraine is a discrete feature that extends across northeastern Wisconsin and into Iron County, Michigan where it is referred to as the Watersmeet Moraine (Attig et al. 1985). The Watersmeet Moraine is a disintegration moraine built during the Winegar-Early Athelstane Phase [3] (~15,000 cal. yr BP) that is correlated with the Port Huron Advance (Attig 1984).

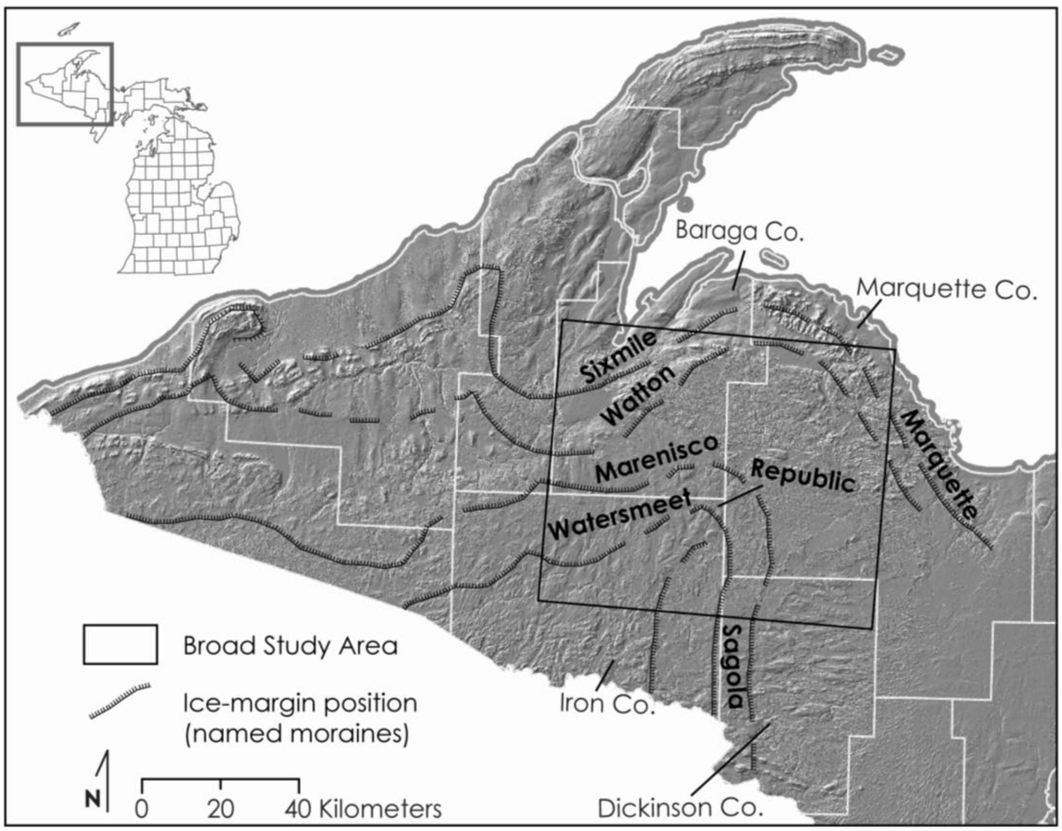


Figure 3.4: A generalized map of the moraines or ice-margin positions in the broad study area (after Attig et al. 1985).

[3] During wastage from a glacial lobe's maximum extent, the ice margin paused or advanced a number of times, from here on out "Phase" refers to these pause and advance cycles (after Attig et al. 1985).

South of the Watersmeet Moraine the landscape is primarily composed of outwash/fluvial surfaces, with many kettles, and small areas of drumlins, whereas to the north of the moraine, the landscape is marked by hummocky bedrock controlled topography with many closed depressions and few lakes (Attig et al. 1985). Moreover, the moraine is composed of gravelly sandy brown till (Peterson 1986). Attig et al. (1985) mapped the Watersmeet Moraine as the Republic Moraine in Marquette County and as the Sagola Moraine in Dickinson County (Figure 3.4). Peterson (1986) suggested that the Sagola Moraine was built by the Green Bay Lobe and consists of calcareous red drift composed of ice contact, stratified sand and gravel; the moraine is marked by hummocky topography with many kettles to the south. The red color of the drift suggests that its ultimate source was the red Precambrian sandstones and shale from the Lake Superior basin (Attig et al. 1985; Peterson 1986).

After the Winegar-Early Athelstane Phase, the margins of the four lobes eventually retreated north, possibly well into the Lake Superior basin, but advanced again to build the Marenisco, Watton, and Marquette/Sixmile moraines (Figure 3.4). The Marenisco Moraine was built by the Green Bay Lobe during the Marenisco-Late Athelstane Phase (approximately between 13,700 and 13,400 cal. yr BP). Unlike the moraines of the Winegar-early Athelstane Phase, the Marenisco Moraine is hard to trace because there is little evidence of sediment collapse. During the Winegar-early Athelstane Phase, the ice advanced over sediment and ice from earlier events, which later resulted in widespread collapse of till and supraglacial sediment, making the ice-margins traceable. However, the Marenisco Moraine forms a subdued and dissected ridge just north of the Winegar/Watersmeet Moraine (Peterson 1982; Attig et al. 1985; Figure 3.4).

Following the Marenisco-Late Athelstane Phase were the Porcupine and Marquette Phases (Attig et al. 1985; Derouin et al. 2007). The Watton moraine, built by the Keweenaw Bay Lobe, formed at the Porcupine ice-margin position which extends from southwestern Baraga County to northeastern Marquette County (Figure 3.4). The western and southern parts of the Lake Superior basin are known to have been ice free approximately between 13,000 and 10,000 cal. yr BP, based on evidence of Lake Agassiz draining eastward through Lakes Superior and Huron at this time (Clayton 1983). Therefore, the Porcupine Phase is speculated to have occurred ~13,000 cal. yr BP (Clayton 1984; Attig et al. 1985).

The last documented glacial phase to have advanced beyond the northern rim of the BSA and southern rim of the Lake Superior basin is known as the Marquette Phase (Attig et al. 1985), previously known as the Marquette readvance (Hughes and Merry 1978; Farrand and Drexler 1985; Lowell et al. 1999). The Keweenaw and Michigamme Lobes built what is known in Baraga County as the Sixmile Moraine, and in Marquette County as the Marquette Moraine; both are composed of red clayey till (Attig et al. 1985). Wood buried in glaciofluvial sediment from the Marquette Phase has been dated at ~ 11,500 cal. yr BP (Hughes and Merry 1978; Lowell et al. 1999; Pregitzer et al. 2000).

The glacial history, outlined above, suggests a maximum of ~ 11,500 years (Marquette Phase) available for soil development in the northern regions of the broad study area ~ 15,000 years (Winegar-Early Athelstane Phase) in the southern regions for pedogenesis.

3.4 Physiography and relief

The landscape encapsulating the broad study area is bedrock-controlled, with uplands ranging from 0 - 205 m in local relief, interlaced with valleys that often contain sandy and gravelly glacial and fluvial deposits. For discussion purposes, the broad study area is separated into six physiographic regions; each region is delineated based on its uniform physical/environmental attributes, such as physiography/relief, soils, hydrology and vegetation (Schaetzl et al. (in prep)). The six sizable physiographic regions (Figure 3.5) that make up ≥ ~ 2 percent of the BSA include, from north to south, the Yellow Dog Plains (Black 1969), Peshekee Highlands (Peterson 1986), Baraga Plains (Doonan and Byerlay 1973), Michigamme Highlands (Brubacker 1975), Gwinn Sandy Terrain (Schwenner 2007), and the Iron Mountain Bedrock Uplands (Schaetzl et al. (in prep).

Local relief for these regions was measured using a DEM raster, at 10 m resolution (USGS, 2009) and using map algebra in ArcMap 10 software (ESRI 2011) to calculate the elevation range in a 250 m circle for each 30-m output cell. The use of similar local relief measures has been successfully applied to other glacial landscapes, as a means of delineating regions (e.g. Stoelting 1989).

Taken together, the Yellow Dog Plains and the Baraga Plains combined make up ~ 2 percent of the BSA. Both are low relief outwash plains, with vast expanses of excessively drained sandy soils, interspersed with poorly drained, organic rich soils (Figures 3.5 and 3.6; Table 3.1). Jack pine forest occupies the dry and sandy soils, whereas black spruce thrives in the wetter areas.

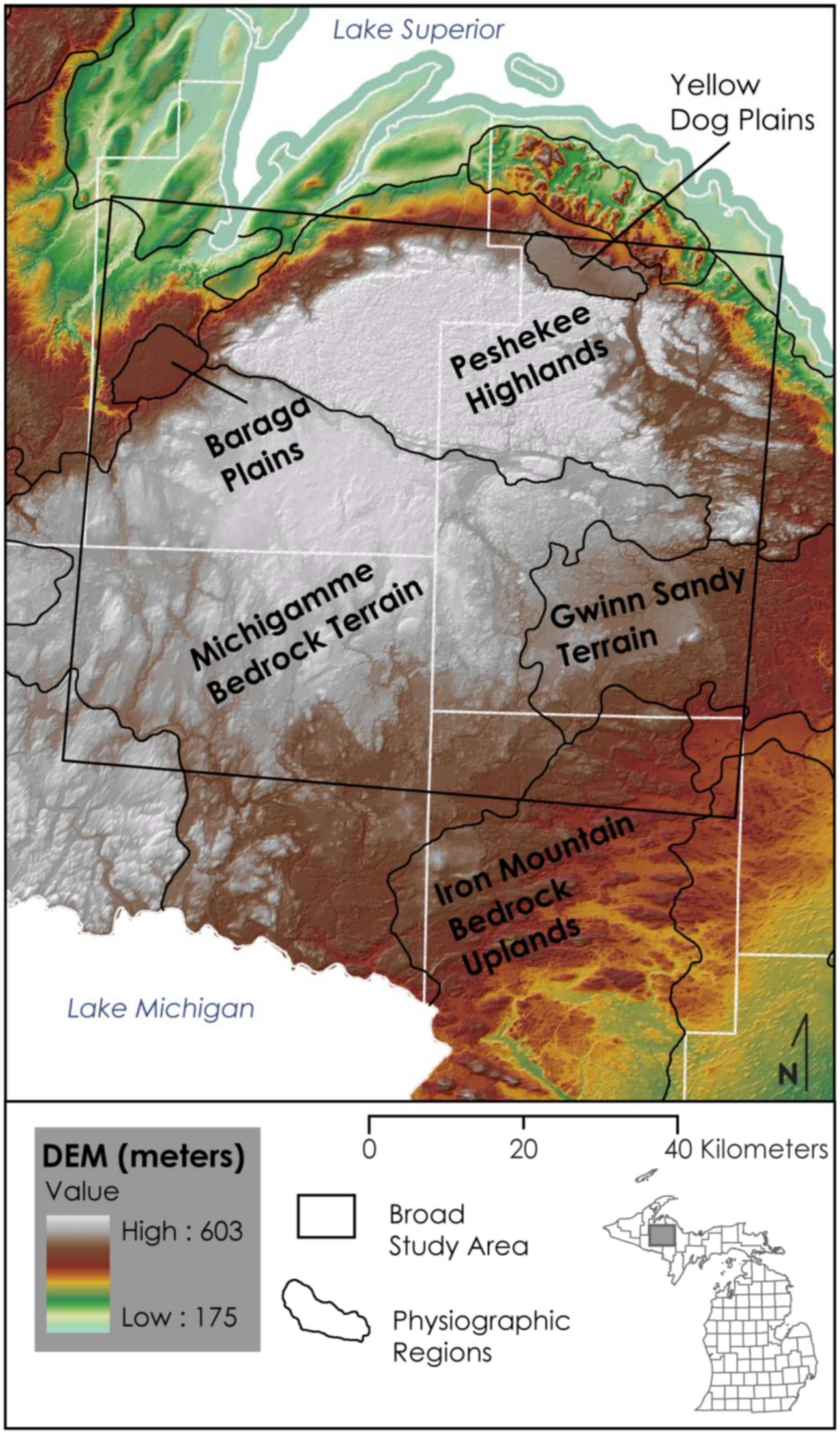


Figure 3.5: Major physiographic regions within the broad study area (Schaetzl et al. (in prep.)).

South of the Yellow Dog Plains and east of the Baraga Plains are the Peshekee Highlands. The Peshekee Highlands total 28 percent of the BSA and have a maximum relief of 205 m (per 250 m radius circle) and an average relief of 30 m. This region is a bedrock-controlled landscape, with poorly drained soils dominating the intervening lowlands, and well drained and moderately well drained sandy soils developing on the uplands (Figures 3.5 and 3.7; Table 3.2). There is a large change in relief – often present as a ragged bedrock escarpment - between the surrounding regions and the Peshekee Highlands; Figure 3.8 illustrates the variability in relief across the region.

Figure 3.6: Photographs of the Mulligan Plains (A) and Yellow Dog Plains (B), both low-relief, excessively well drained, sandy outwash plains, interspersed with poorly drained soils. Photograph (A) by M. Luehmann and (B) by R. Schaetzl.

Table 3.1: Description of the Yellow Dog Plains and Baraga Plains physiographic regions (after Schaetzl et al. (in prep)).

Region	Physiography/relief	Soils/sediments	Hydrology	Presettlement vegetation
Yellow Dog Plains	Low relief (~ 7 m average), sandy, outwash or glaciolacustrine plain.	Excessively drained, sandy soils dominate, with wet soils on the southern margin.	Yellow Dog River flows across the southern margin.	Jack and red pine on dry expanses, northern hardwoods at edges, and bogs on wettest, southern margins.
Baraga Plains	Low relief (~ 4 m average), sandy, dry, outwash or glaciolacustrine plain.	Excessively drained, sandy soils dominate, with very poorly drained on the SE margin.	Very little surface water.	Jack and red pine forests and barrens. Conifer swamps on SE margin.

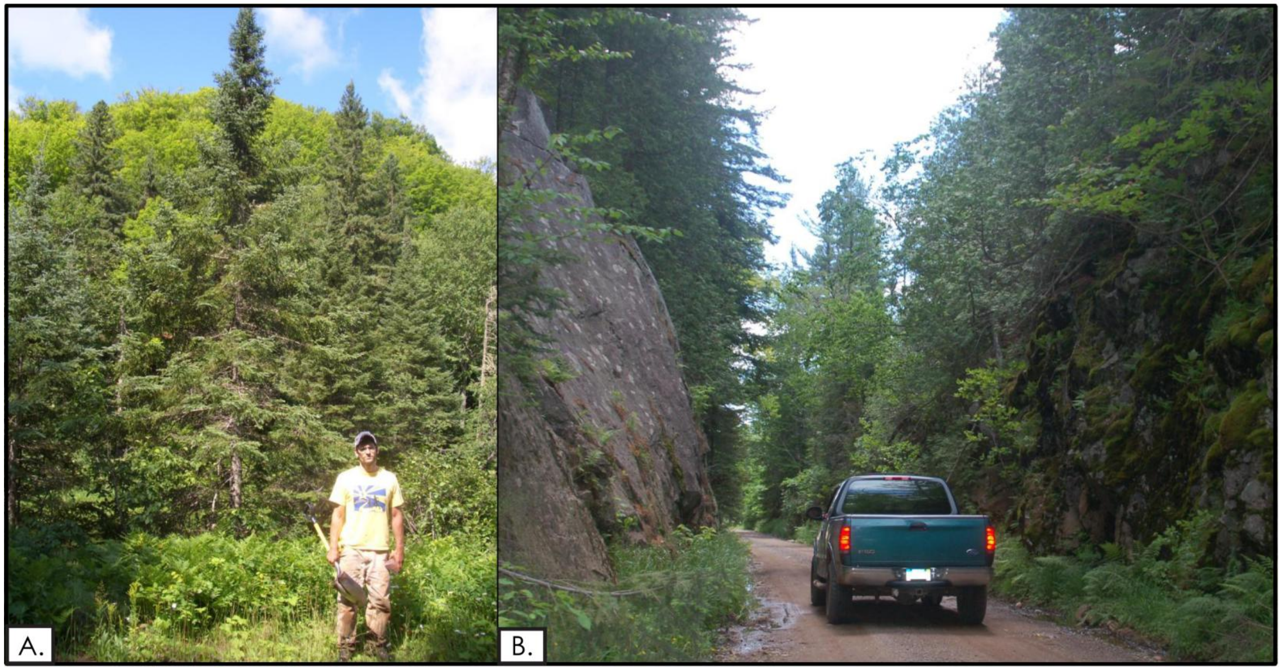


Figure 3.7: Photographs at the base of a resistant, high-relief, Precambrian bedrock knob within the Peshekee Highlands. Photograph (A) by L. Safford, and (B) by R. Schaetzl.

Table 3.2: Description of the Peshekee Highlands physiographic region (after Schaetzl et al. (in prep)).

Region	Physiography/relief	Soils/sediments	Hydrology	Presettlement vegetation
Peshekee Highlands	Bedrock-controlled landscape of high relief (~ 30 m average) and irregular topography. Glacially eroded bedrock knobs and drift-filled valleys.	Well drained, shallow soils on uplands, poorly drained soils and Histosols in lowlands. Many upland soils have a thin loess cap.	Major upland of the western UP, forming a regional drainage divide. Abundant lakes, few through-flowing streams.	Sugar maple-hemlock forests on uplands, conifer swamps in lowlands.

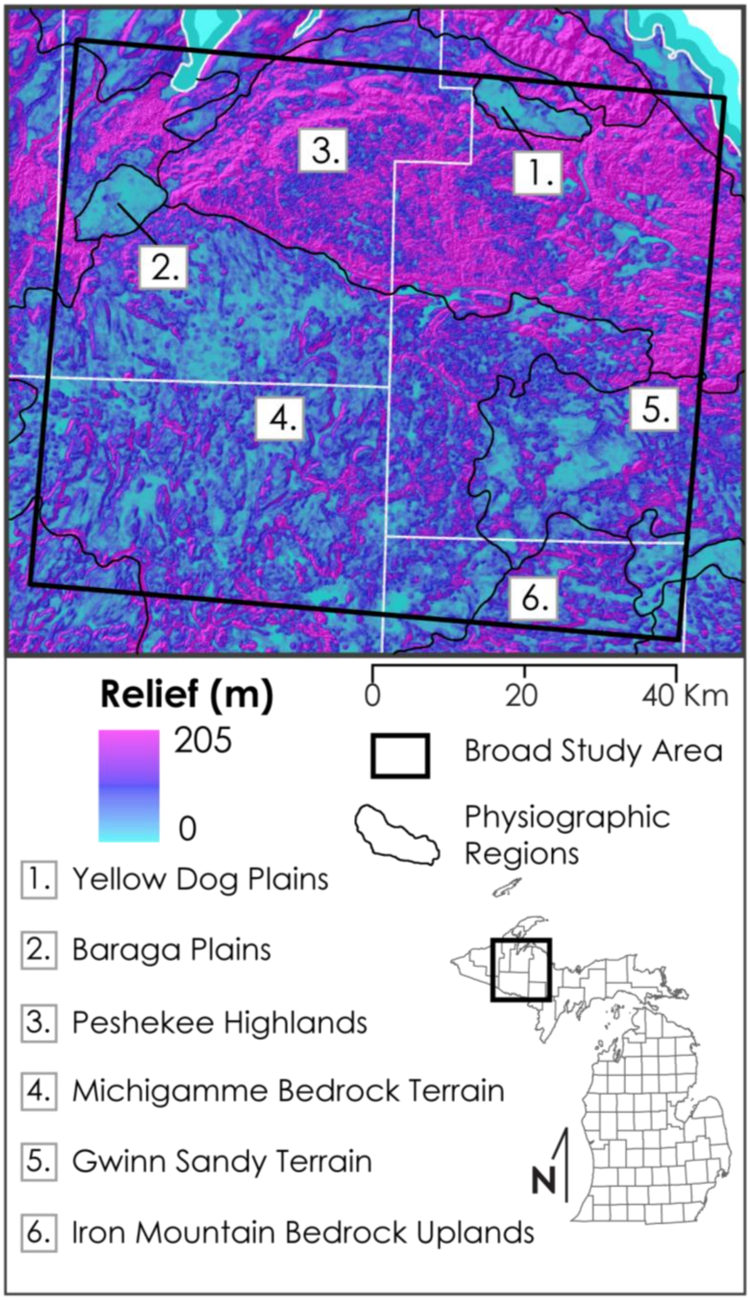


Figure 3.8: Local relief variation within the broad study area, and the physiographic region boundaries.

The Michigamme Bedrock Terrain is the largest, homogeneous physiographic region in the western Upper Peninsula. In addition, it is the largest of the six physiographic regions within the broad study area, occupying 45 percent of the region. This region has a highly deranged drainage pattern, with moderate relief (averaging ~ 13 m), and many small, linear bedrock knobs (Figures 3.5 and 3.8; Table 3.3). The linear bedrock knobs are mantled with thin regolith composed of a silt-rich cap overlying sandy loam till or outwash. East of the Michigamme Bedrock Terrain is the Gwinn Sandy Terrain, a moderate relief landscape, with variable topography and sandy parent materials (Figure 3.9). Occupying the southeastern corner of the BSA is the Iron Mountain Bedrock Uplands. This region is dominantly underlain by Archean granites and gneisses (as opposed to slate directly to the west and north in the Michigamme Bedrock Terrain). The Iron Mountain Bedrock Uplands consist of rolling terrain with isolated hills and well drained sandy and loamy soils.

A heterogeneous mixture of parent materials and drift types occupies the Peshekee Highlands and Michigamme Bedrock Terrain - the two largest physiographic regions within the BSA. However a commonality between these two regions is that the glacial drift here is sandy, and commonly overlain by a thin, silt-rich and very fine sand loess cap (Figure 3.9).

Table 3.3: Description of the Michigamme Bedrock Terrain, Gwinn Sandy Terrain, and Iron Mountain Bedrock Uplands physiographic regions (after Schaetzl et al. (in prep)).

Region	Physiography/relief	Soils/sediments	Hydrology	Presettlement vegetation
Michigamme Bedrock Terrain	Hummocky and occasionally incised plains with moderate relief; many bedrock knobs. Drift is sandy, thin in many places but can be, locally, thick. Many areas could simply be bedrock-influenced ground moraine.	Moderately well drained, or drier, soils on uplands. Many poorly drained soils, and Histosols, in lowland swamps. Many soils have a thin mantle of loess.	Deranged drainage, many swamps and lakes. General, broad upland that is also a regional drainage divide; low stream gradients. Many wetlands are expansive.	Sugar maple-yellow birch-hemlock forests on uplands, conifer swamps in lowlands.
Gwinn Sandy Terrain	Heterogeneous area of moderate relief but widely variable topography and sandy soils. Topography includes hummocky areas, incised stream valleys, small bedrock outcrops and bedrock-influenced terrain, and low, rolling terrain on thick drift.	Generally sandy soils that span a wide range of drainage classes. Parent materials are typically sandy glaciofluvial materials. Histosols common in lowlands, especially in the west.	Complex hydrology, with swamps in lowlands; uplands are often very dry and sandy.	Heterogeneous mix of pine and hardwood forests, as well as spruce-cedar-fir stands in certain areas.
Iron Mountain Bedrock Uplands	Rolling, moderate relief terrain with numerous bedrock-cored knobs and isolated hills, usually sandstone. Heterogeneous mix of parent materials and drift types, but most areas are sandy. Strong west-to-east, regional, topographic slope.	Well drained, sandy loam soils formed in till and glaciofluvial materials, on uplands. Small areas of Histosols in lowlands, between bedrock knobs.	Eastwardly draining streams, some swamps. Generally a well-drained, upland landscape.	Mix of northern hardwoods (sugar maple-basswood,-hemlock-yellow birch) on uplands; conifer swamps in lowlands. Some areas of mostly pine.

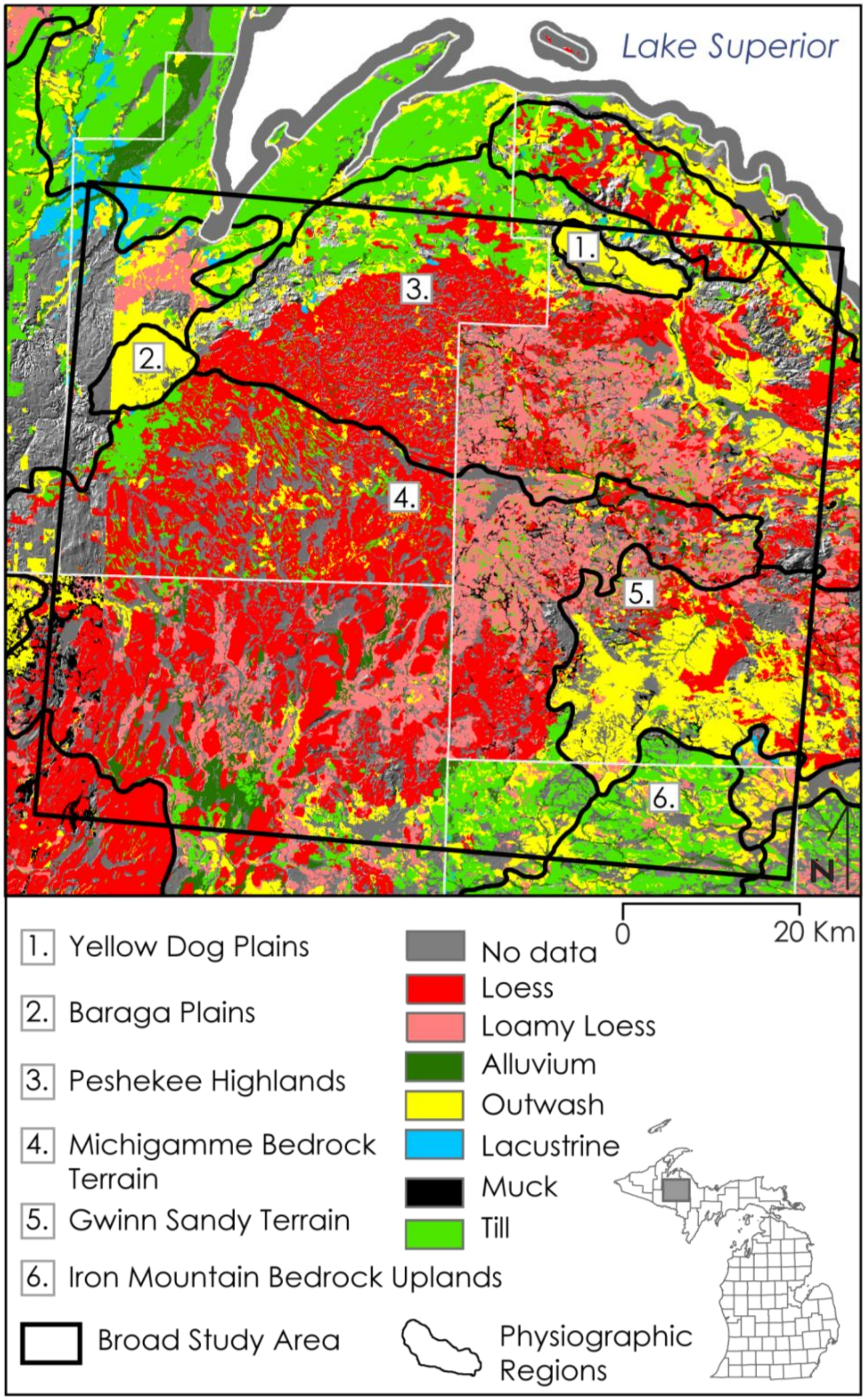


Figure 3.9: Upper solum parent materials within the broad study area (after Berndt 1988; Linsemier 1989; Schwenner 2007).

3.5 Climate and vegetation

The mean annual temperature (1971-2000) for Champion, in central Marquette County, is ~ 4° C, with a mean January temperature of ~ -12°C and mean July temperature of ~ 18°C (National Climatic Data Center 2002). Total mean annual precipitation is ~ 84 cm, of which ~ 54 cm falls between May and October (National Climatic Data Center 2002). Snowfall generally occurs from September through April, and becomes more prevalent further from the lake (higher elevations average annually > 500 cm). The mean annual snowfall for the period 1971-2000 in Champion is 350 cm (http://www.weatherreports.com). Although current winds are multidirectional due to seasonal variations, the dominant wind is from the northwest (Eichenlaub et al. 1990; Arbogast and Packman 2004).

The vegetation of this region varies based on soils, elevation and landscape position (Barrett et al. 1995). The uplands are dominated by sugar maple (*Acer saccharum*), aspen (*Populus*), red maple (*Acer Rubrum*), and yellow birch (*Betula alleghaniensi*), with admixtures of some coniferous tree species, while the lowlands are generally occupied by mixed conifer swamp species such as black spruce (*Picea mariana*), northern white cedar (*Thuja occidentalis*), and balsam fir (*Abies balsamea*) (Comer et al. 1995; Figure 3.10).

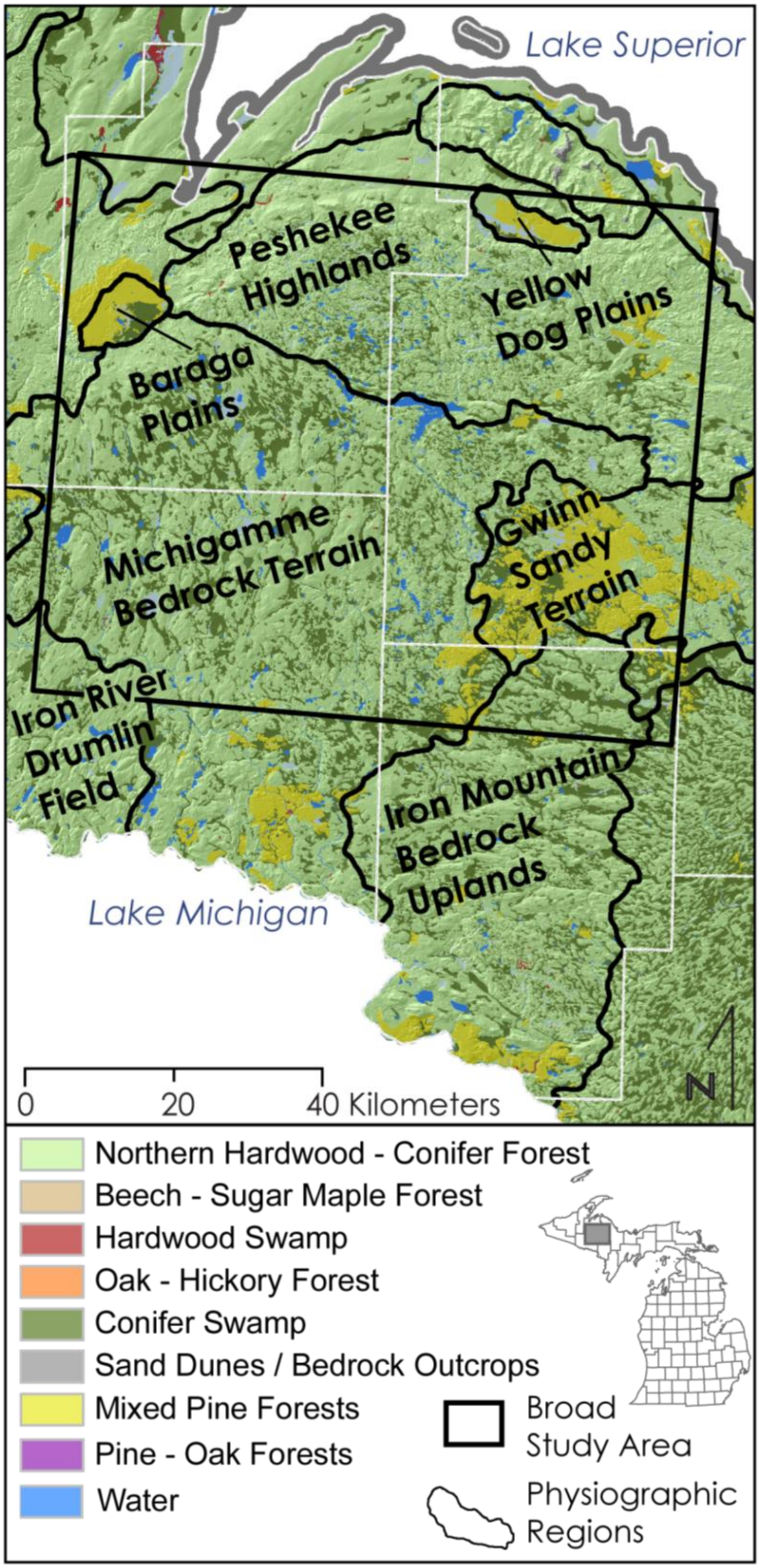


Figure 3.10: Presettlement vegetation of the broad study area (after Comer et al. 1995).

3.6 Soils

Soils within the broad study area mostly consist of well and moderately well drained Spodosols on the high-relief bedrock (or drift) uplands. Upland soils here have largely formed in silt loam-textured loess, generally ranging between 40 and 60 cm in thickness, overlying loamy and sandy glacial drift, or bedrock (Berndt 1988; Linsemier 1989; Schwenner 2007). Valleys and depressions between the uplands are commonly occupied by organic rich, poorly and very poorly drained Histosols, with Histic epipedons that range from 120 and to 130 cm in thickness. For the sake of discussion and relevance to the project, only the seven dominant upland loess-derived (loessal) soil series will be discussed in this thesis. "Dominant," in this case, refers to loessal soil series mapped on uplands within the BSA that cover > ~1.5 percent of the broad study area.

The seven upland loessal soils are quite similar morphologically, with only subtle differences in their loess cap thickness, surface texture, presence/absence of a fragipan and/or presence/absence of an argillic horizon. In this section I will (1) discuss the spatial distribution of the dominant loessal soils within the broad study area and their surface textures and loess cap thicknesses, and (2) compare the major morphologic features, including diagnostic horizons, of these soils.

3.6.1 Spatial distribution of surface textures and loess cap thicknesses

The seven dominant loessal soil series in the broad study area are Champion, Michigamme, Petticoat, Dishno, Keewaydin, Goodman, and Wabeno (see Tables 3.4, 3.5, and 3.6 for taxonomic subgroup names). Each of these soil series covers a minimum of ~ 9,000 hectares within the BSA, and combined, these soils cover ~ 176,000 hectares, or 31 percent, of the broad study area.

For the sake of organization, I grouped the seven soil series based on their surface texture (i.e., based on first mineral horizon), as described in their official soil descriptions (Tables 3.4, 3.5, and 3.6; http://soildatamart.nrcs.usda.gov). All of these series have either silt loam, cobbly silt loam, or cobbly fine sandy loam surface textures (Berndt 1988; Linsemier 1989; Schwenner 2007). On its southern margins, the BSA has mainly been mapped with loessal soil series that have silt loam surface textures (Goodman and Wabeno series), whereas cobbly silt loam loessal soil series are mapped in the western and central regions (Champion, Michigamme, Petticoat, and Dishno series) and one cobbly fine sandy loam loessal soil series (Keewaydin series) is mapped in the northern and central regions (Berndt 1988; Linsemier 1989; Schwenner 2007; Figure 3.11).

Table 3.4: Characteristics of loess with cobbly silt loam surface textures (http://soildatamart.nrcs.usda.gov).

	Soil series			
Characteristics	**Champion**	**Michigamme**	**Petticoat**	**Dishno**
Counties mapped within	Baraga, Iron, and Marquette	Baraga and Marquette	Baraga and Iron	Marquette
Taxonomic family	Coarse-loamy, mixed, superactive, frigid Oxyaquic Fragiorthods	Coarse-loamy, mixed, superactive, frigid Fragic Haplorthods	Coarse-loamy over sandy or sandy-skeletal, mixed, active, frigid Alfic Haplorthods	Coarse-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Oxyaquic Haplorthod
Parent materials	Modified loamy eolian material and in the underling gravelly sandy or loamy glacial till	Silty or loamy mantle over loamy glacial till underlain by igneous or metamorphic bedrock	Modified silty eolian material and in the underlying sandy glacial till	Silty or loamy eolian deposits over sandy and gravelly till underlain by igneous or metamophic bedrock
Landform	Ground moraines and end moraines	Ground moraines	Ground moraines	Bedrock controlled moraines
Surface texture	Cobbly silt loam	Cobbly silt loam	Cobbly silt loam	Cobbly silt loam
Eolian cap thickness	~ 56 cm	~ 64 cm	~ 97 cm	~ 56 cm
Texture at the *LD	Gravelly sandy loam	Gravelly fine sand	Very gravelly loamy sand	Very stony loamy sand
Coverage within the broad study area	~ 69,000 hectares	~ 22,000 hectares	~ 15,000 hectares	~ 9,000 hectares

***LD - Lithologic discontinuity**

Table 3.5: Characteristics of loess with Cobbly fine sandy loam surface textures (http://soildatamart.nrcs.usda.gov).

Soil Series	Counties mapped within	Taxonomic family	Parent materials	Landform	Surface texture	Eolian cap thickness	Texture at the *LD	Coverage within the broad study area
Keewaydin	Marquette	Coarse-loamy over sandy or sandy-skeletal, mixed, superactive, frigid Typic Haplorthods	Loamy and silty eolian deposits and in the underlying till	Bedrock controlled moraines	Cobbly fine sandy loam	~ 51 cm	Gravelly loamy sand	~ 35,000 hectares

***LD - Lithologic discontinuity**

Table 3.6: Characteristics of loess with silt loam surface textures (http://soildatamart.nrcs.usda.gov).

Soil Series	Counties mapped within	Taxonomic family	Parent materials	Landform	Surface Texture	Eolian cap thickness	Texture at the *LD	Coverage within the broad study area
Goodman	Marquette and Iron	Coarse-loamy, mixed, superactive, frigid Alfic Haplorthods	Loess and in the underlying till	Drumlins and moraines	Silt loam	~ 64 cm	Sandy loam	~ 15,000 hectares
Wabeno	Iron	Coarse-loamy, mixed, superactive, frigid Alfic Oxyaquic Fragiorthods	Loess and the underlying loamy and sandy till or glacial mud-flow sediment	Drumlins and moraines	Silt loam	~ 61 cm	Gravelly sandy loam	~ 12,000 hectares

***LD - Lithologic discontinuity**

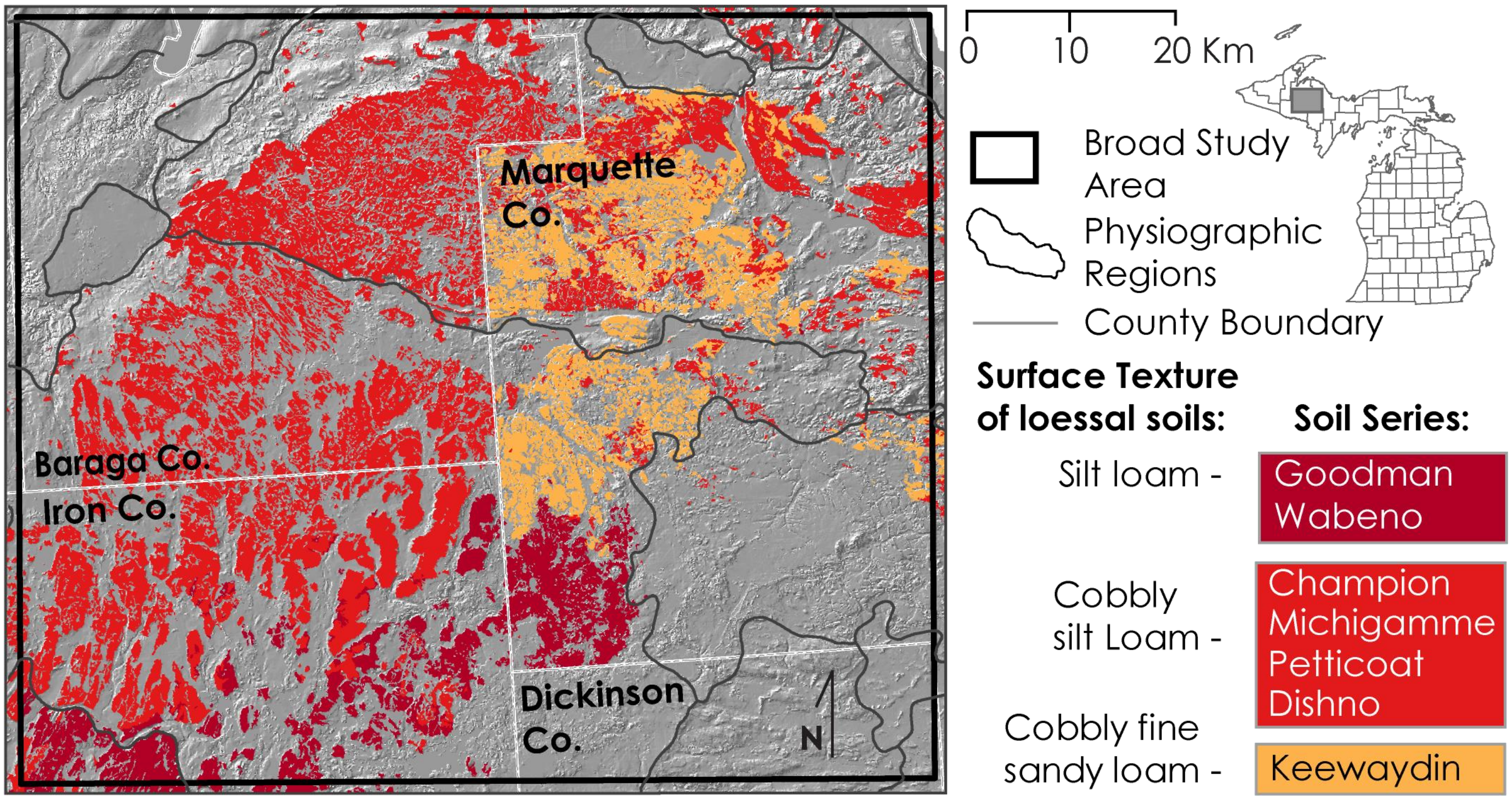


Figure 3.11: A map of the surface textures of the seven dominant loessal soil series in the broad study area (Berndt 1988; Linsemier 1989; Schwenner 2007).

The surface texture map (and later, the loess cap thickness map) has several distinct breaks at county boundaries. These breaks are due to the different publication ages between county-level soil survey projects, within the broad study area. The Baraga County soil survey was published in 1988, Dickinson County in 1989 and the Iron County soil survey was published in 1997, whereas the most recent county soil survey, the Marquette survey, dates to 2007. During the period 1997 and 2007, series nomenclature and definitions had changed. At the Marquette-Baraga border there is a disjunct between soil series; the Champion soil series was dominantly being mapped in Baraga County, whereas the subsequently developed Keewaydin series was mapped only in Marquette County. Wikgren (personal communication 2011) explained the introduction of the Keewaydin series, during the Marquette survey project, as follows. Marquette County, like Baraga County, has many hectares of soils that have developed in ~50-60 cm of silty-fine sandy eolian material overlying sandy drift. In Marquette County, however, these soils have slightly coarser eolian material overlying till, *and* they rarely have fragipans. Soils with the latter morphology were mapped as Keewaydin. Champion soils, mapped in Baraga County, have siltier surface textures, and a well-developed fragipan. This mapping "break" suggests that there may be a difference in loess texture as one traverses from Baraga to Marquette County. The change in fragipan expression, across the same traverse, is less important to this research. Obviously, neither of these transitions is abrupt or located immediately at the county border, and thus, the disjunct in series nomenclature is due to the age of soil survey projects.

Based solely on data from NRCS county soil surveys, it appears that the broad study area has finer surface textures (silt loam) in the southern and south-central regions and coarser surface textures (cobbly fine sandy loam) in the northern and north-east regions (Figure 3.11). However, it is important to note that, where the NRCS has mapped loessal soils with a cobbly silt loam surface texture, these soils largely have silt loam fine earth fractions, but by volume have 15-35 percent cobbles (Soil Survey Manual 1993). Here, we are only concerned with each soil's fine-textured sediment, i.e., the sediment between the cobbles and gravel which was potentially deposited via eolian processes. Thus, for this study, both cobbly silt loam and silt loam surface textures are considered equivalent, because the "cobbly" modifier may be a reflection of mixing processes, which have mixed cobbles and gravels that were below the loess to the surface (or nearer to it).

After examining the NRCS county soil surveys, it became obvious that, generally, soil series with *thicker* loess caps are mapped in the southern and south-central regions, whereas soil series with *thinner* loess caps are mapped in the northern and north-central regions of the BSA (Figure 3.12).

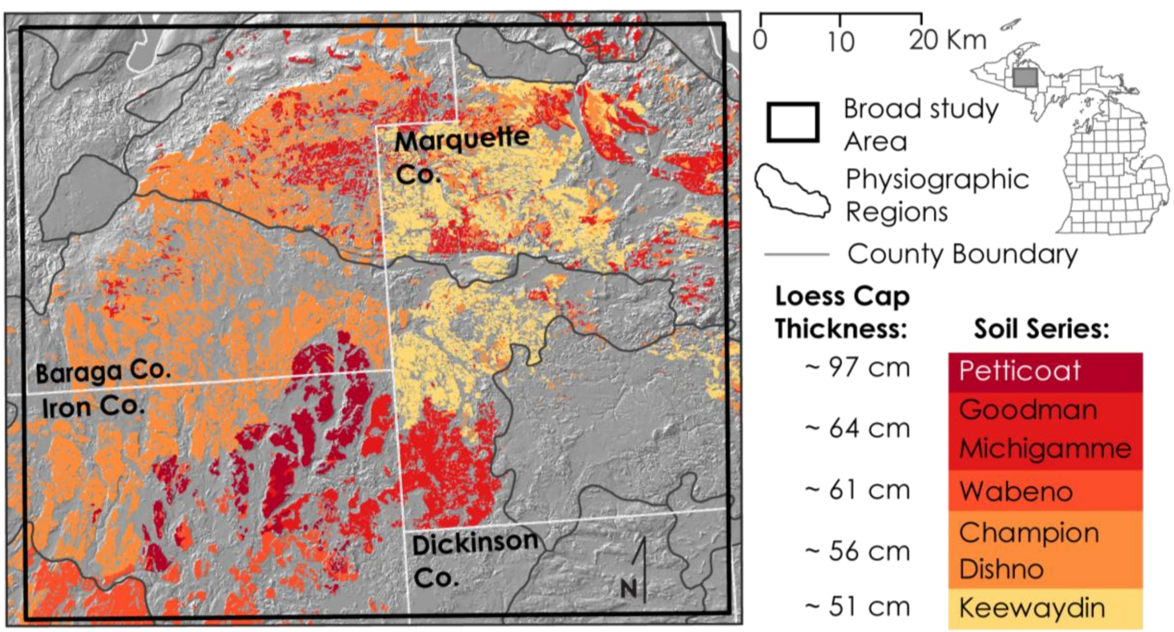


Figure 3.12: Map of loess thickness, based on the seven dominant loessal soil series in the broad study area (Berndt 1988; Linsemier 1989; Schwenner 2007).

Further observations of the NRCS maps indicate that (1) the thickest loessal soil series (Petticoat) is dominantly mapped in the southern and very center region of the broad study area and (2) thickness trends for the broad study area generally point to a southerly and south-westerly source area, because the loess has a southwest-northeast thinning trend (Figure 3.12).

3.6.2 Major loessal soils and comparing their diagnostic horizons

The seven dominant upland loessal soils within the broad study area are very similar morphologically, with only subtle differences in horizonation. Taxonomic designations for the seven loessal soils are largely dependent on loess cap thickness, surface texture, presence/absence of a fragipan and/or argillic horizon, and profile thickness. Figures 3.13 and 3.14 were developed in order to better illustrate the subtle differences and similarities between the seven dominant soils. These figures compare the Champion series, the most abundant soil series mapped within of the BSA, to the remaining six upland loessal soil series within the broad study area.

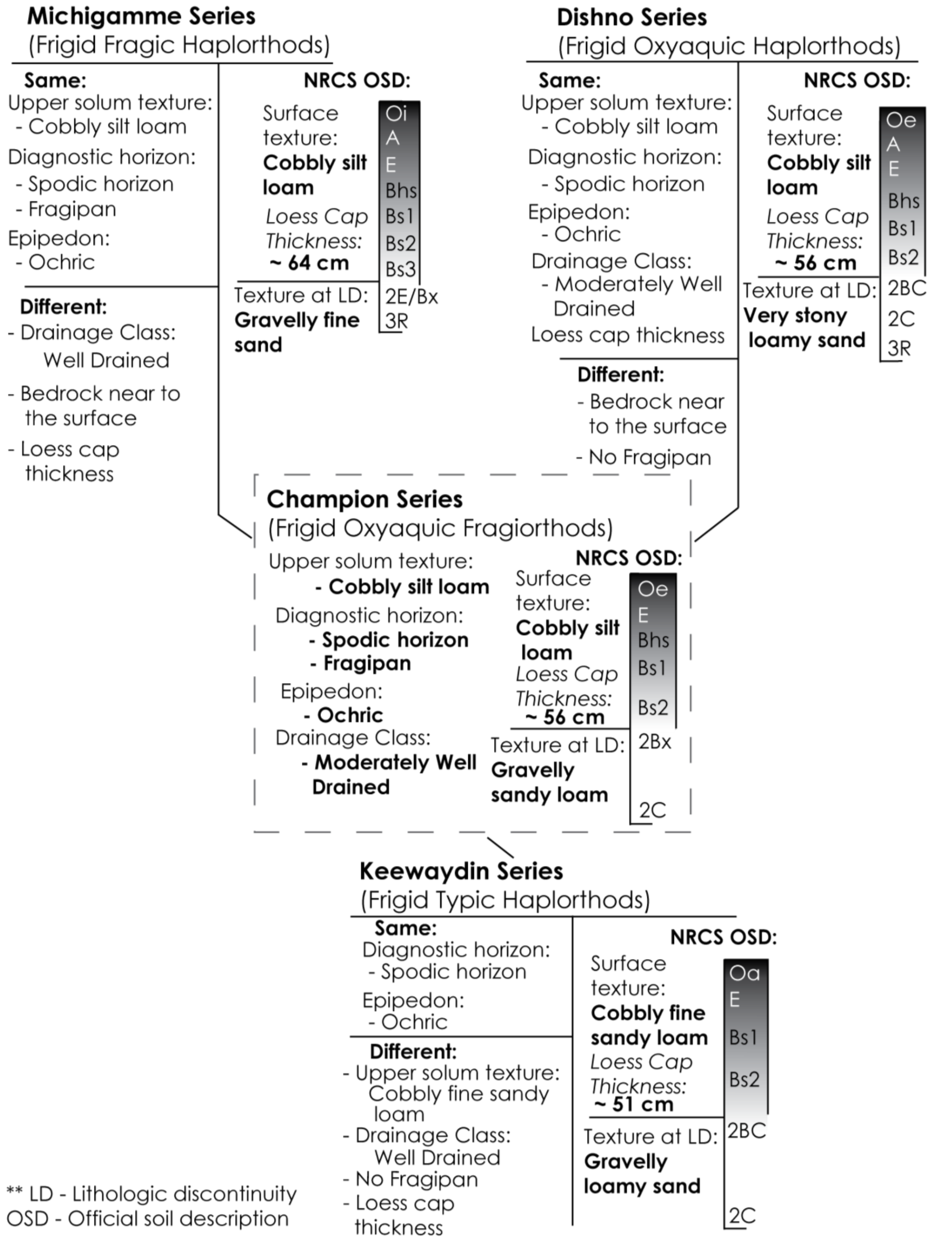


Figure 3.13: A comparison of the similarities and differences between the Champion series, the most abundant mapped loessal soil series within the broad study area, and the Michigamme, Dishno, and Keewaydin series. (http://soildatamart.nrcs.usda.gov).

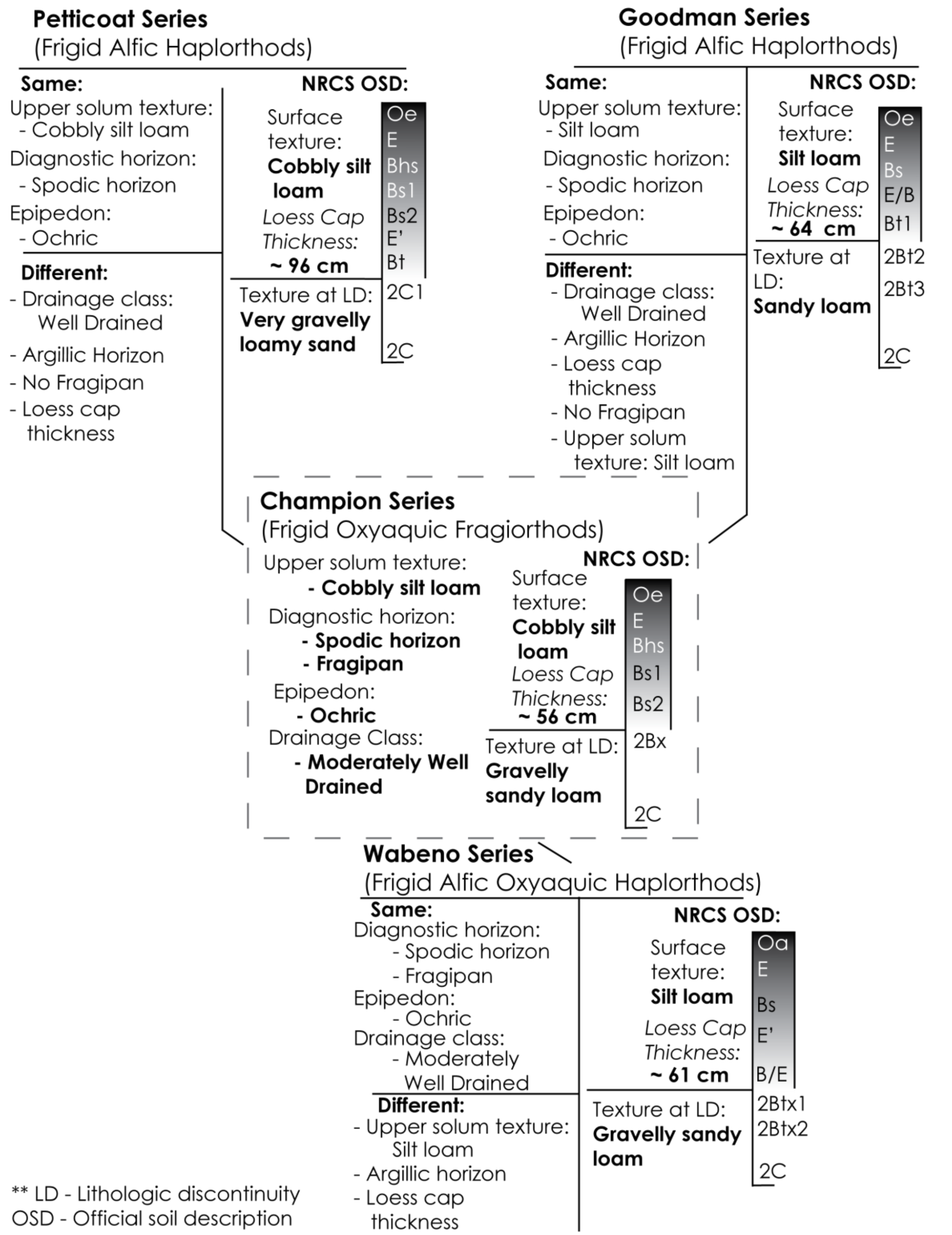


Figure 3.14: A comparison of the similarities and differences between the Champion series, the most abundant mapped loessal soil series within the broad study area, and the Petticoat, Goodman, and Wabeno series. (http://soildatamart.nrcs.usda.gov).

The Champion series covers > ~ 69,000 hectares of the broad study area, and is the most dominant loessal soil series mapped within the broad study area (Tables 3.4 and 3.5). Second in dominance is the Keewaydin series which covers ~ 35, 000 hectares. The Champion and Keewaydin series are morphologically similar in that they both have a spodic horizon, an ochric epipedon, and have developed in loess and underlying loamy sand glacial drift (Figure 3.13; Table 3.7). The Keewaydin series has a cobbly fine sandy loam surface texture, and is commonly mapped in the northeastern, northern and north-central regions of the BSA, whereas the Champion series has a cobbly silt loam surface texture and is mapped in the northern, western and central regions of the BSA (Figure 3.12). Unlike the Champion soil profile (Oe-E-Bhs-Bs1-Bs2-2Bx-2C), the Keewaydin series has a "simple" soil profile (Oa-E-Bs1-Bs2-2BC-2C) (Figure 3.13). Keewaydin soils do not have a Bhs horizon (i.e., evidence of illuvial accumulation of organic matter and humus and the accumulation of sesquioxides Fe and Al), or a Bx horizon (firm, brittle and/or high bulk density horizon- fragipan)

Table 3.7: Comparing the diagnostic character between the Champion and Keewaydin soil series (http://soildatamart.nrcs.usda.gov).

Diagnostic Character	Soil Series: Champion	Soil Series: Keewaydin
Ochric epipedon	**Yes**	Yes
Subsurface diagnostic horizon	**- Spodic - Fragipan**	- Spodic
Loess cap thickness	**~ 56 cm**	~ 51 cm
Drainage class	**Moderately well drained**	Well drained
Upper solum texture	**Cobbly silt loam**	Cobbly fine sandy loam
Lower most horizon texture	**Gravelly loamy sand**	Very cobbly loamy sand
Shallow to bedrock	**No**	No

(http://soildatamart.nrcs.usda.gov). However, in context to this project, both soils have developed in loess and the underlying loamy sand glacial till. The main difference is in surface texture and the development of a fragipan.

The Champion, Michigamme, and Dishno series all have a cobbly silt loam surface textures, a spodic horizon and an ochric epipedon (Table 3.8). The Michigamme and Dishno series, like the Keewaydin series, are mapped in the northern and north-central regions of the BSA. However, the Michigamme and Dishno series differ from the Keewaydin series in both having a Bhs horizon, and being shallow to bedrock (Figure 3.13; Table 3.8). Dishno soils lack a fragipan, whereas Champion and Michigamme soils have developed a fragipan at the lithologic discontinuity (Figure 3.13; Table 3.8).

Table 3.8: Comparing the diagnostic character between the Champion, Michigamme and Dishno soil series (http://soildatamart.nrcs.usda.gov).

Diagnostic Character	**Soil Series**		
	Champion	Michigamme	Dishno
Ochric epipedon	**Yes**	Yes	Yes
Subsurface diagnostic horizon	**- Spodic - Fragipan**	- Spodic - Fragipan	- Spodic
Loess cap thickness	**~ 56 cm**	~ 64 cm	~ 56 cm
Drainage class	**Moderately well drained**	Well drained	Moderately well drained
Upper solum texture	**Cobbly silt loam**	Cobbly silt loam	Cobbly silt loam
Lower most horizon texture	**Gravelly loamy sand**	Firm loam	Loamy coarse sand
Shallow to bedrock	**No**	Yes	Yes

In the southern and south-central regions of the BSA, the Petticoat, Goodman, and Wabeno series are commonly mapped (Figures 3.11 and 3.12). Like Champion soils, the Petticoat, Goodman, and Wabeno series have either a silt loam or cobbly silt loam surface texture, a spodic horizon and an ochric epipedon (Table 3.9). However, unlike Champion soils, Petticoat, Goodman, and Wabeno soils all have a Bt horizon (argillic horizon – accumulation of silicate clay) (Figure 3.14). Furthermore, the Petticoat, Goodman, and Wabeno series have a slightly thicker loess cap (~ 60 cm to 90 cm) in comparison to Champion soils in which the loess cap is roughly 55 cm thick (Figure 3.14).

Table 3.9: Comparing the diagnostic character between the Champion, Petticoat, Goodman, and Wabeno soil series (http://soildatamart.nrcs.usda.gov).

Diagnostic Character	**Soil Series**			
	Champion	Petticoat	Goodman	Wabeno
Ochric epipedon	**Yes**	Yes	Yes	Yes
Subsurface diagnostic horizon	**- Spodic - Fragipan**	- Spodic - Argillic	- Spodic - Argillic	- Spodic - Fragipan - Argillic
Loess cap thickness	**~ 56 cm**	~ 97 cm	~ 64 cm	~ 61 cm
Drainage class	**Moderately well drained**	Well drained	Well drained	Moderately well drained
Upper solum texture	**Cobbly silt loam**	Cobbly silt loam	Silt loam	Silt loam
Lower most horizon texture	**Gravelly loamy sand**	Very gravelly loamy sand	Loamy sand	Gravelly sandy loam
Shallow to bedrock	**No**	No	No	No

After examining the above data, I conclude that the majority of upland loessal soils mapped in Iron County have a thicker loess cap, in comparison to what was found in Baraga and Marquette Counties, and thus, the NRCS mapped out different soil series for each county soil survey. The Petticoat series was limited to Iron County with a loess cap ~ 97 cm thick, whereas Champion was mapped in Baraga County with a loess cap ~ 56 cm thick, and in Marquette County Keewaydin was mapped with a loess cap ~ 51 cm thick. Additionally, loessal soils in Iron County have finer and more clay-rich upper solum textures, as suggested by the loessal soils with argillic horizons (Petticoat, Goodman, and Wabeno), and silt loam (Goodman and Wabeno) and cobbly silt loam surface textures (Petticoat). In comparison, in Baraga and Marquette Counties, loessal soils mapped there do not have an argillic horizon (Champion, Dishno, Michigamme, and Keewaydin) and have cobbly fine sandy loam (Keewaydin) and Cobbly silt loam (Champion, Michigamme, and Dishno) surface textures.

Within the broad study area, the seven dominant upland loessal soil series are similar in that they are all two storied soils, mapped on uplands, and have formed in a finer-textured eolian cap (loess) and underlying loamy and sandy glacial till. In addition, they have spodic horizons and ochric epipedons (Tables 3.4, 3.5, 3.6, 3.7, 3.8 and 3.9). The main differences among these soils is the subsurface diagnostic horizon (e.g. having a fragipan and/or argillic horizon), upper solum texture, and the thickness of the loess cap (Tables 3.4, 3.5, 3.6, 3.7, 3.8 and 3.9). However, soil horizonation and taxonomic delineations are of lesser concern for this project. The main focus here is the presence/absence of the loess cap, loess cap thickness, and the surface texture of the loess. Generally, based on the NRCS soil surveys, loessal soil series with a thicker eolian mantle and a finer surface texture are mapped in the southern regions of the BSA, whereas loessal soils with a thinner eolian mantle and a coarser surface texture are mapped in the northern regions.

3.7 Summary of Broad Study Area

The broad study area, set within the western Upper Peninsula of Michigan, is complex in its morphology and varies in topography. Multiple glacial episodes are evident for this area, based on characteristics such as soil color, texture, lithology, and the terrain of the till sheets left by these glaciers. The most recent glacial advance not only influenced the topography in the western Upper Peninsula through its grinding and plucking mechanics, but also by its meltwater streams. In western and northwestern Marquette County, the terrain is dominated by high-relief, bedrock knobs that are interspersed with under-fit meltwater streams, small outwash plains, and steep, V-shaped valleys. Here, on bedrock uplands, soils with fine sandy loam mantles often overly glacial outwash, till, and/or Precambrian bedrock. South of this region, the terrain becomes more subdued, as the thicknesses of glacial deposits increases and the distances between bedrock uplands become larger. Generally, this landscape is wetter than the northern regions, and the upland soils are thicker and have a silt loam mantle, opposed to a fine sandy loam mantle.

4. Methods

4.1 Field Methods

In preparation for entering the field, potential loess sample locations were identified and coded in a geographic information system (GIS). Loess "target locations" were required to meet the following three criteria:

(1) At the site, the NRCS had mapped soils with a loess cap

(2) The site consisted of a broad and flat upland

(3) The site was in a woodlot, thereby negating major anthropogenic disturbances due to cultivation.

Theoretically, sites with these three criteria would have well preserved loess and would be representative of the loess here. Target locations were determined by inspecting three data sets in a GIS: (1) topographic maps of the Upper Peninsula of Michigan – USGS digital raster graphic (DRG), (2) a 10-meter digital elevation model (DEM), and (3) county-level SSURGO (digital soils) data (Figure 4.1).

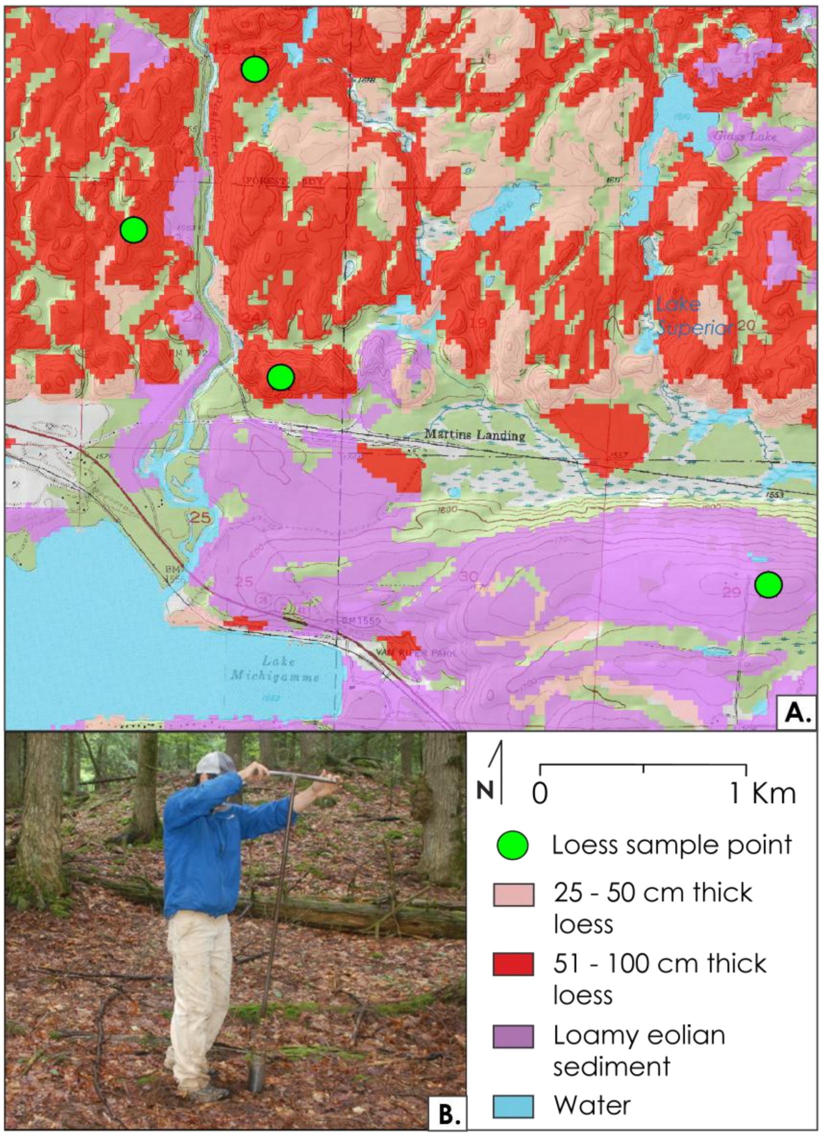


Figure 4.1: (A) Map illustrating the distribution of loessal soils on uplands within the broad study area, as indicated by the NRCS. Green dots are locations where loess samples were taken. (B) Sampling loess at a target location using a standard hand-held auger. Photograph by R. Schaetzl.

Once in the field, at each target location, the site was carefully explored using a short handled landscaping shovel to “peel open” multiple soils and hand texture the uppermost mineral horizon. This procedure was done in order to identify soils that had the following four criteria:

(1) At least one mineral horizon
(2) Low percentage of cobbles – increasing the likelihood of an eolian deposit
(3) An upper horizon that was silty and/or had a very fine sandy texture.

If the soil met criteria 1-3, then it was more closely inspected to determine if it met the last criterion: a silty or very fine sand textured upper mineral horizon, with either bedrock directly below or sediment that was coarser in texture, in relation to the material above. Soils that met these criteria were deemed optimal for sampling, and had the highest likelihood of being representative of the original loess that was deposited in the broad study area.

Target locations were deemed unsuitable for sampling, and therefore “passed up,” if they exhibited any of these four criteria:

(1) Bedrock at the surface
(2) Organic material (Oa, Oi, Oe) overlying bedrock
(3) Percentage of cobbles and gravels > ~ 80 percent
(4) Sand, loamy sand or coarser textures in the upper profile.

During June, July, and August 2010, loess samples were collected in the broad study area, using either a hand-held bucket auger or a short-handle landscaping shovel. A bucket auger was preferred when sampling loess > ~ 50 cm (not very often). Once a site was located that met the four sampling criteria (outline above), the silt mantle’s thickness was determined by digging a small exploratory pit - roughly 50 cm in diameter and 30 cm deep (depth varied with loess cap thickness). Hand texturing was then used to identify the total thickness of the loess cap - the distance between the top of the first mineral horizon and the estimated lithologic discontinuity (to either bedrock or glacial drift) below. At each site, approximately 1 kilogram of soil was taken from the clean, freshly exposed loess profile provided by the exploratory pit. The sample was collected throughout the entire loess cap; however the loess sample was discontinued at ~ 7 cm above the lithologic discontinuity, i.e., the boundary between the silt mantle and the coarser substrate or bedrock. This procedure limited the amount of mixed material in the sample, which commonly exists at the base of the loess column or weathered bedrock. The objective of this sampling procedure was to sample the most representative loess for that area, and loess that had not been too contaminated by in-mixing of sediment from below. Soil samples were sequentially labeled. Additionally, at each site, the location of the sample was stored in a GIS file, using a laptop computer equipped with ArcMap 10 software (ESRI 2011) and a built in GPS unit. Additional attribute information, digitally recorded at each site included:

(1) Loess mantle thickness

(2) The landform type or land-use, e.g., bedrock upland or woodlot

(3) Loess quality

Loess quality is a subjective measure based on loess thickness and texture; a rank of 0 implied that the sediment seemed too coarse for classical silty loess. A rank of 10 suggested that the loess was very silty and the loess cap was thick. For safe keeping, these attributes were also noted in a field notebook.

4.2 Laboratory Methods

Each loess sample was individually ground with a mortar and wooden pestle, after being either air dried and/or oven-dried at 30°C. The ground sample was then passed through a 2 mm sieve to eliminate sediment or organic material > 2 mm dia. The remaining fine earth material was sent through a sample splitter three times in order to homogenize the sample. All soil samples were then prepared for particle size analysis (psa), which was performed using a Malvern Mastersizer 2000 laser particle size analyzer (Malvern Instruments Ltd., Worcestershire, UK). Sample preparation, for particle size analysis, included placing ~ 1 g of soil in a 25 ml vial and adding 5 ml of dispersant solution and 10 ml of distilled water to the vial. The dispersing solution was 35.70 g $(NaPO_3)_6$ and 7.94 g Na_2CO_3 mixed into one liter of water (Kilmer and Alexander 1949). Each vial with the soil sample and dispersion solution was then shaken for 2 hours on a rotating table to properly disperse the sediment.

In recent years, laser diffractometry has generally replaced the traditional sieve-pipette method for particle size analysis (Sperazza et al. 2004; Arriaga et al. 2006). Although the data produced using these two methods are highly correlated (Arriaga et al. 2006), differences in the estimation of the clay fraction do occur (Buurman et al. 1997). The laser method commonly underestimates the amount of < 2 μm clay, when compared to the pipette method (Loizeau et al. 1994; Beuselinck et al. 1998). For this reason, Konert and Vandenberghe (1997) suggested that a clay-silt break of 8 μm be utilized in laser diffractometry, in order to facilitate any comparisons with traditional particle size analysis data. In-house data analyses produced the highest correlations between clay contents determined by pipette vs. laser diffractometry when the clay-silt break for the latter is set at 6 μm (Hobbs et al. 2011). This is the procedure followed in this study.

In order to make the data set more robust and produce kriged surfaces of greater accuracy with less error, an additional 59 samples collected by M. Bigsby and R. Schaetzl during previous fieldwork campaigns were added to my data set. The Bigsby and Schaetzl samples were collected using the same procedures as noted above, and incorporate many of the samples in the southwestern portion of the broad study area. The aggregated data set included data from 267 sites (Figure 4.2).

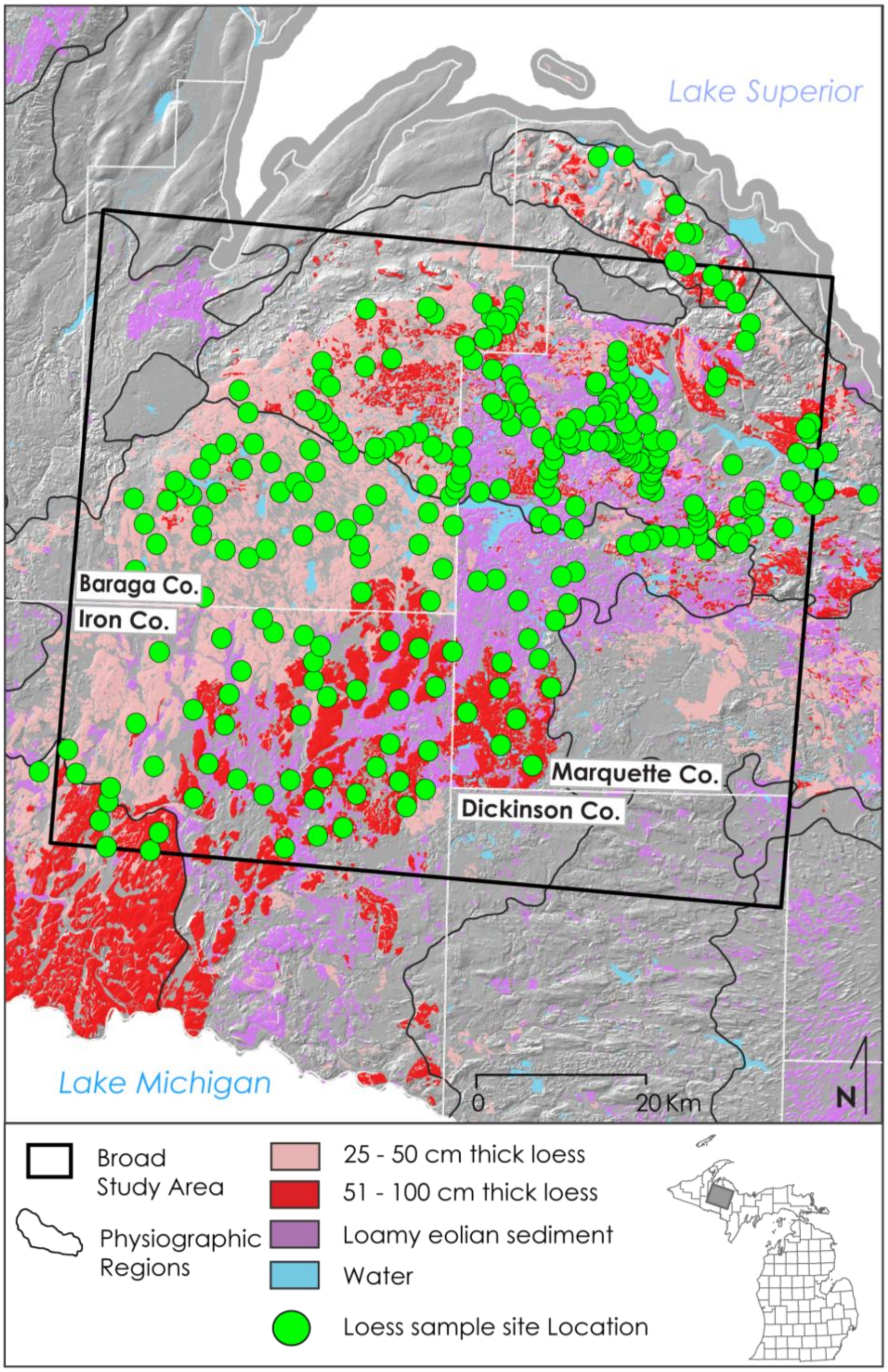


Figure 4.2: The distribution of loess samples across the broad study area, including a few points taken north and south of the study area.

4.3 Post Processing

After psa was performed on each sample, the particle size data were exported and formatted for spreadsheet software. Excel (Microsoft Inc., Redmond, WA) was used to plot continuous textural curves from 0 to 2000 micrometers. Using ArcMap 10 (ESRI 2011) software, data for each sample (e.g., loess thickness, loess quality, and percent - sand, silt, clay, very fine sand, medium silt, fine silt, etc.) were entered into a GIS attribute table, according to site number. The ArcMap shapefile and field notes were re-examined to clarify proper geographic location and to confirm that the site included the target location criteria listed above.

Using the geostatistical wizard module of ArcMap (ESRI 2011), data for the various particle size data fractions were spatially interpolated using ordinary kriging with a smoothing factor of 0.6 (Oliver and Webster 1990; Hobbs et al. 2011; Scull and Schaetzl 2011). Separate surfaces were created for several of the major loess texture variables in order to examine the spatial variations within the broad study area and to identify which of the variables were most useful for loess classification/discrimination. Map products included multiple continuous surface maps, using isolines to illustrate loess cap thickness, loess quality, mean and modal grain size, ratios of raw textural data, and clay-free contents of numerous particle size fractions for the Peshekee Loess.

5. Results and Discussion

In the past, soil maps have identified loess as a surficial deposit in Baraga, Iron, and Marquette Counties, Michigan (Flint 1971; Berndt 1988; Linsemier 1989; Schwenner 2007; Scull and Schaetzl 2011). However, until now, the loess mantle’s thickness, textural character, and potential source area(s) have not been the focus of mapping or research efforts. This chapter, therefore, focuses on characterizing the loess located in Baraga, Iron, and Marquette Counties – the region of loess formally known as the Iron County Loess Sheet and the Peshekee Loess Sheet

(Scull and Schaetzl 2011). I will begin by presenting and discussing how the research data set was "cleaned-up" and the logistics behind the clean-up process. The remaining sections of this chapter center on the loess itself. First, I will introduce and define several "eolian textural curve" types, for samples found within the broad study area. I will then individually illustrate the eolian textural curve type categories and their distributions within the broad study area. Next, I will present and discuss the spatial characteristics of the Peshekee Loess. In this section, trends in loess thickness and distributions of various silt and fine sand contents will be shown using filled contour, continuous surface maps, created by ordinary kriging in ArcMap10. I will then discuss the distribution of modal particle size values throughout the study area. Next I will name and characterize four smaller, loess "sections" within the study area. Finally, by combining the eolian textural curve type information with the trends in loess thickness, modal particle size, and the distribution of silt and sand contents, I will suggest presumed source area(s) for the four loess sections within the study area, and defend these interpretations.

5.1 Data Set "Clean-up"

To my knowledge, this thesis is the first study to evaluate loess deposits situated at the extreme margins of much larger and thicker - regional scale - loess region. Here, at the margins of the broad study area, loess deposits are thin (between ~ 20 and 80 cm), highly dissected, and vary considerably in texture. Many sites/soils completely lack eolian materials (more common in the northern regions of the broad study area), while other sites/soils are questionable, as to whether or not the surficial sediment was deposited by eolian processes - judging by hand-field texturing. Thus, many sites were not sampled due to site criteria and/or the absence of loess, and other sites were sampled even though they were, at the time, debatable. The sediments at some sites were uncertain because it was difficult to field-determine the surface texture; I was unable to estimate the ratio between the 25-75 µm fraction to 250-1000 µm fraction, simply by hand-field texturing. As a result of these sampling strategy issues, the loess sample data set required a second look, akin to a quality control exercise. Therefore, after each sample was processed for particle size analysis (psa), it was evaluated before being incorporated into the final data set. This evaluation process, from here on out, is referred to as the data set “clean-up” process.

The data set clean-up process began by analyzing each sample’s continuous textural curve, in order to assure that the sample had an abundance peak within the 25-75 µm fraction. This type of textural signature is typical of silty eolian materials (Smith 1942; Ruhe 1954; Frazee et al. 1970; Olson and Ruhe 1979; Smalley and Smalley 1983; Schaetzl and Hook 2008; Schaetzl 2008; Schaetzl and Loope 2008; Scull and Schaetzl 2011). A sample that had a continuous textural curve with a mode in the 250-1000 µm fraction would not be suggestive of eolian sediment, but instead is more likely to have been glacial outwash and/or glacial till. Samples that were believed to have eolian signatures were found to have either a single textural mode in the 25-75 µm fraction, or a bimodal textural curve - with a dominant mode in the 25-75 µm fraction and a secondary mode, usually in the 250-1000 µm fraction. The 25-75 µm fraction likely signifies the eolian sediment within each sample, whereas the peak in 250-1000 µm fraction points to contributions from the underlying parent material. Thus, the next step in the clean-up process was to categorize or assign each sample to an eolian textural curve (ETC) type. As a result of this analysis procedure, five dominant ETC types emerged:

Type 1 - Unimodal silt curve: one mode in the 25-75 µm fraction.

Type 2 - Bimodal silt curve: two modes, with the dominant mode in the 25-75 µm fraction and a second mode in the 250-1000 µm fraction.

Type 3 - Bimodal sand curve: two modes, with the dominant mode in the 250-1000 µm fraction and a second mode in the 25-75 µm fraction.

Type 4 - Silt shoulder curve: one mode in the 25-75 µm fraction, and a change in the slope of the textural curve near the 250 µm fraction. (For example, the curve has a steep negative slope throughout the 125-250 µm fraction, but it transitions to a gradual slope near the 250-500 µm fraction. The area of gradual change is referred to as a “shoulder” in this thesis.

Type 5 - Sand shoulder curve: one mode in the 250-1000 µm fraction, and a change in the slope of the textural curve near the 25-75 µm fraction. (For example, the curve has a moderately steep positive slope throughout the 25-75 µm fraction, but it transitions to a steep positive slope in the 250-1000 µm fraction).

Some samples did not have a single mode in the 25-75 µm fraction or the 250-1000 µm fraction, but instead had a single mode between ~ 100 µm and 125 µm. Samples with a textural mode within the 100-125 µm fraction do not match any of the five ETCs described above. This type of sediment texture is usually not associated with eolian processes, because it is likely too coarse for loess. Likewise, the sediment is too fine to be typical of the local glacial till and outwash. Samples that had a single mode within the 100-125 µm fraction did not have a *typical* continuous textural curve representative of the loess deposits within the broad study area (Figure 5.1). Thus, these samples that did not exhibit textural curve types 1-5 and had a mode within the 100-125 µm fraction were considered to have a type 0 ETC.

Type 5 and 0 samples have very similar continuous textural curves, however, type 5 samples have a mean modal particle size of ~ 243 µm whereas the type 0 samples have a mean modal particle size of ~ 102 µm (Figures 5.1 and 5.2). Eolian textural curve types 1-5 have a mode or shoulder curve usually in one or two size fractions, i.e., in the 25-75µm fraction and/or the 250-1000 µm fraction. However, type 0 curves do not have a modal size in either of these two size fractions. Type 0 samples have a mode within the 100-125 µm fraction, suggesting that they have a different sedimentologic origin (Figures 5.1 and 5.2). After analyzing each sample’s continuous textural curve and classifying the loess samples to an eolian textural curve type, seven samples had type 0 ETCs (Figure 5.1). Field notes revealed that these seven samples had either a loess quality of 0, as often indicated by a hand-field texture that felt too coarse for loess or a high pit/mound density; suggesting a poorly preserved or contaminated and mixed loess deposit (Table 5.1). Floraturbation may have mixed the original loess deposits to a point where the deposits no longer have a peak in the 25-75 µm fraction.

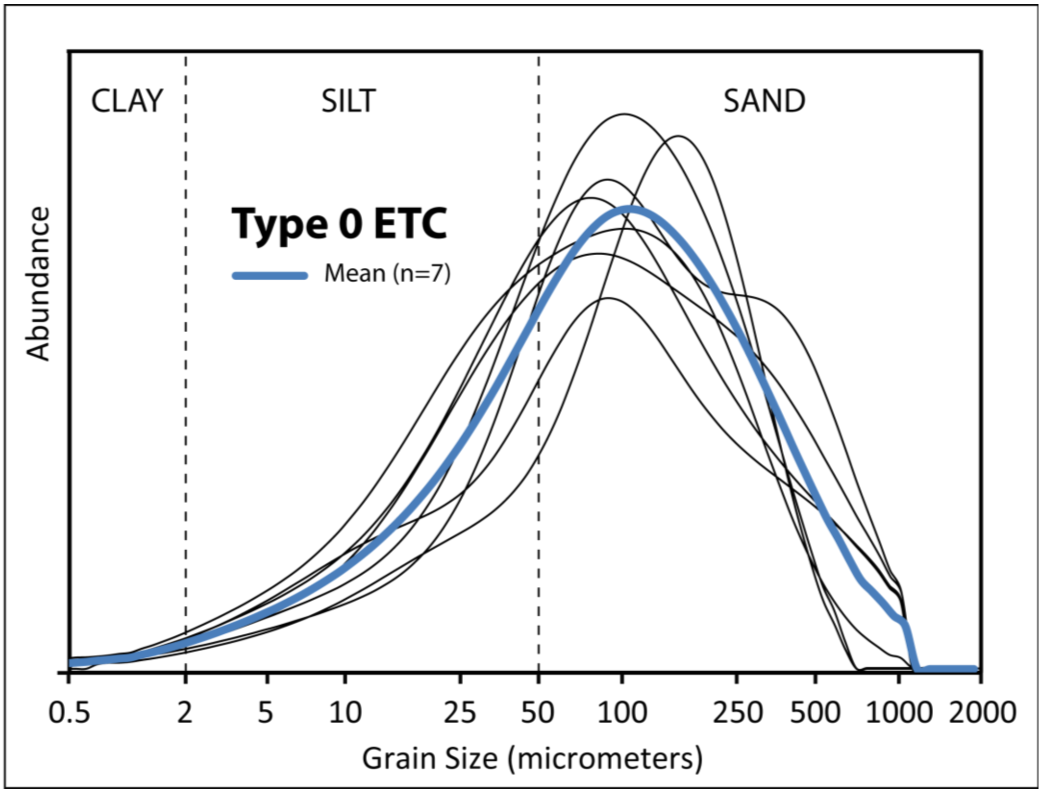


Figure 5.1: Samples curves that were eliminated from the kriging data set, as a result of not having a type 1-5 ETC. See Table 5.1 for more details.

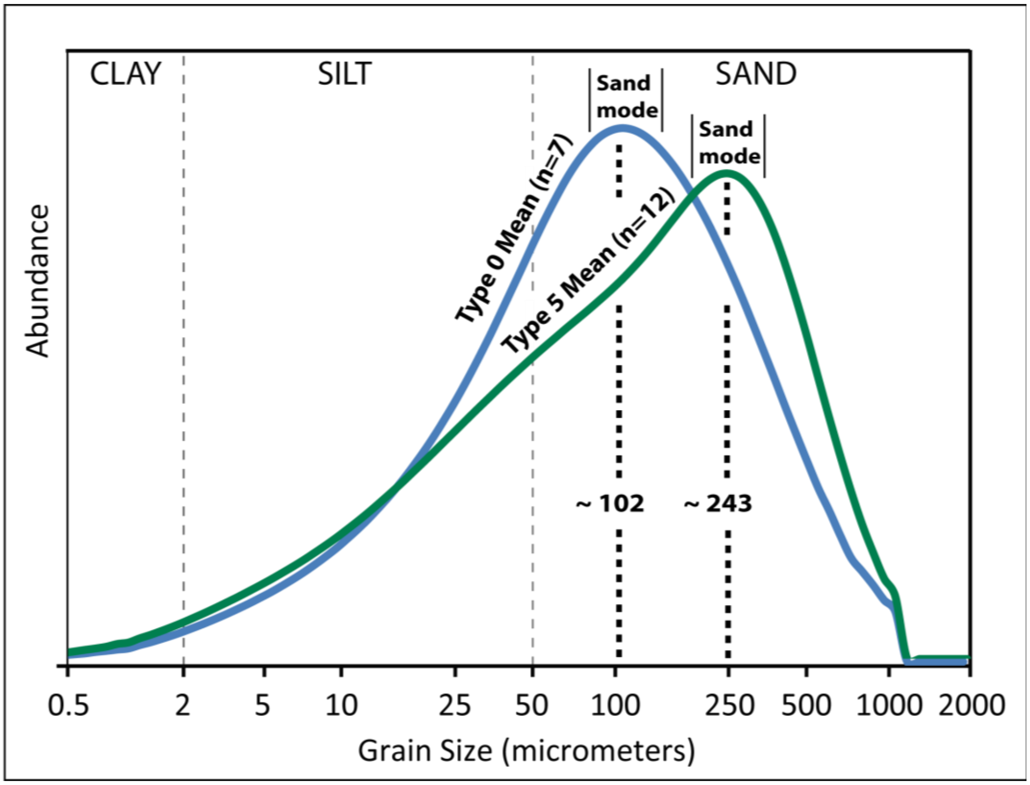


Figure 5.2: Differences between type 0 and type 5 eolian textural curves. Mean values are shown.

Table 5.1: Characteristics of type 0 eolian textural curves.

Type 0 ETC (n=7)	Loess thickness	Modal particle size	Coarse silt (35-50 µm)	Fine sand (125-250 µm)	Fine through medium sand (125-500 µm)
	cm	*µm*	*Percent Clay-free*		
Min.	20.0	78.9	5.9	18.1	29.6
Max.	60.0	163.0	10.4	32.2	49.1
Mean	39.3	101.9	8.9	21.9	35.9
Standard Deviation	11.5	26.5	1.5	4.6	6.2

Six out of the seven type 0 samples were collected within the Peshekee Highlands physiographic region, where textural curve types ranged from 1 to 5 and field notes revealed that loess deposits were often absent (Figure 5.3). There was only one type 0 ETC near the southern margins of the broad study area within the Michigamme Bedrock Terrain physiographic region. An examination of the approximate site location in ArcMap suggested that this sample was likely taken from the shoulder slope of a bedrock-upland, instead of the appropriate summit position. The sub-optimal landscape position may have caused post-depositional processes to incorporate more sand into any loess that may have initially existed there, or may have exacerbated the erosion of loess; leaving behind very little loess and/or mainly the coarsest eolian material. In sum, seven type 0 ETC samples were eliminated from the Peshekee Loess final data set because these seven samples were not representative of eolian materials within the broad study area.

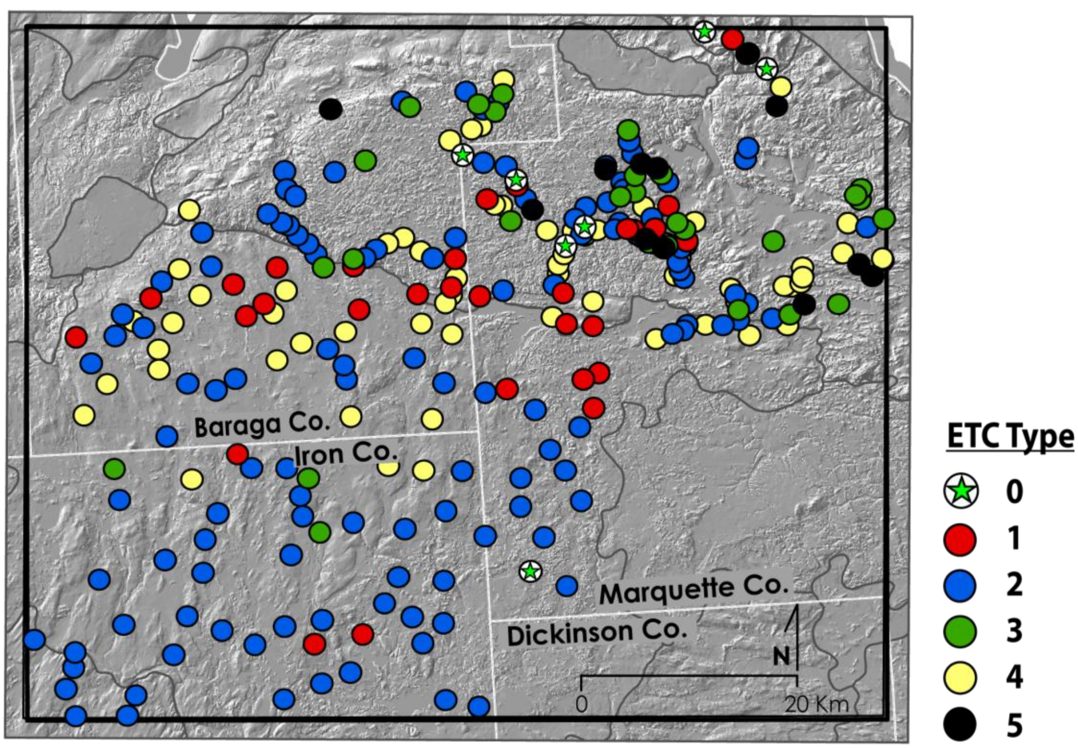


Figure 5.3: The spatial distribution of ETC types 0-5 throughout the broad study area.

This thesis utilized a unique eolian soil texture sample strategy, which was necessitated because of the landscape's high-relief, and thin and discontinuous eolian mantle. The sampling technique involved subjective measures, e.g., loess thickness and the presence/absence of loess, and therefore also required an innovative data set clean-up process. After running particle size analysis on all samples, it was evident that not all samples have similar textural curves. Thus, I grouped the loess samples into five dominant eolian textural curve types. The five continuous textural curves are defined as ETC type categories, one of which has been assigned to each soil sample taken within the broad study area.

5.2 Characteristics of Loess within the Broad Study Area

As explained above, the soil (eolian sediment) samples collected within the broad study area, generally exhibit one of five eolian textural curve types. Each curve has either a unimodal, bimodal, or shoulder shape. In this section, I will define, compare, illustrate and discuss the five ETC types found within the broad study area. In addition, I will discuss the mean modal particle size fractions and the percentage of various particle size fractions within each ETC category. Lastly, I will illustrate the spatial distribution of eolian textural types throughout the broad study area.

5.2.1 Eolian Textural Curve Type Categories

5.2.1.1 Type 1: Unimodal Silt Curves

Of the 267 loess samples from the broad study area, 30 were assigned a type 1 eolian textural curve. These samples are the siltiest loess samples; they have a unimodal curve with the modal particle size in the 25-75 µm fraction (Table 5.2). Type 1 samples have a mean modal particle size in the very coarse silt fraction (48.7 µm) (Figure 5.4; Table 5.2). The loess thicknesses for type 1 ETC sites ranged from 20 cm to 95 cm, respectively, and the mean loess thickness for these 30 sites was 40 cm (Table 5.2).

In the past, loess has commonly been defined by its size (between ~ 20 and 75 µm), transport mechanism, source, and preservation (Smith 1942; Ruhe 1954; Frazee et al. 1970; Olson and Ruhe 1979; Smalley and Smalley 1983; Schaetzl and Hook 2008; Schaetzl 2008; Schaetzl and Loope 2008; Stanley and Schaetzl 2011). Type 1 samples have a range of modal particle size fractions, from medium silt (~ 28 µm) to coarse, very fine sand (~ 79 µm), and a mean modal particle size of 48.7 µm (Table 5.2). Generally, the modal particle size of these samples is within the traditional loess size fraction. In terms of a source, the broad study area was repeatedly glaciated during the Pleistocene Epoch (Hughes and Merry 1978; Clayton 1984; Attig et al. 1985; Peterson 1985; Lowell et al. 1999) supplying both silt and sand sized sediments, along with strong winds for possible eolian transport. The uplands within the broad study area were likely the first stable landscapes, and thus, would have provided a sink and/or a surface that could have preserved eolian sediment. Thus, type 1 samples support data found in NRCS county-level soil surveys, Flint (1971), Scull and Schaetzl (2011), and Bigsby (2010); silt-rich deposits in this area are found overlying bedrock or drift, they are often found on uplands, and likely originated as loess.

Figure 5.4 illustrates the textural curves of all 30 type 1 samples from the broad study area. These samples have a mean total clay-free silt content (2-50 µm) of ~ 54 percent and have a mean medium sand content (250-500 µm) of ~ 4 percent (Table 5.2). Type 1 samples have a very high percentage of silt and a low percentage of the medium and coarser sand fractions, compared to sample types 2-5, respectively (Table 5.2). Sample types 2-5 have mean total clay-free silt contents of ~ 49, ~ 31, ~ 46, and ~ 26 percent, respectively, and have mean medium sand contents that range between ~ 10 and 20 percent (Tables 5.2, 5.3, 5.4, 5.5 and 5.6). Thus, samples assigned a type 1 ETC are different texturally and likely in other characteristics, e.g., thickness and preservation, than are those samples assigned types 2-5.

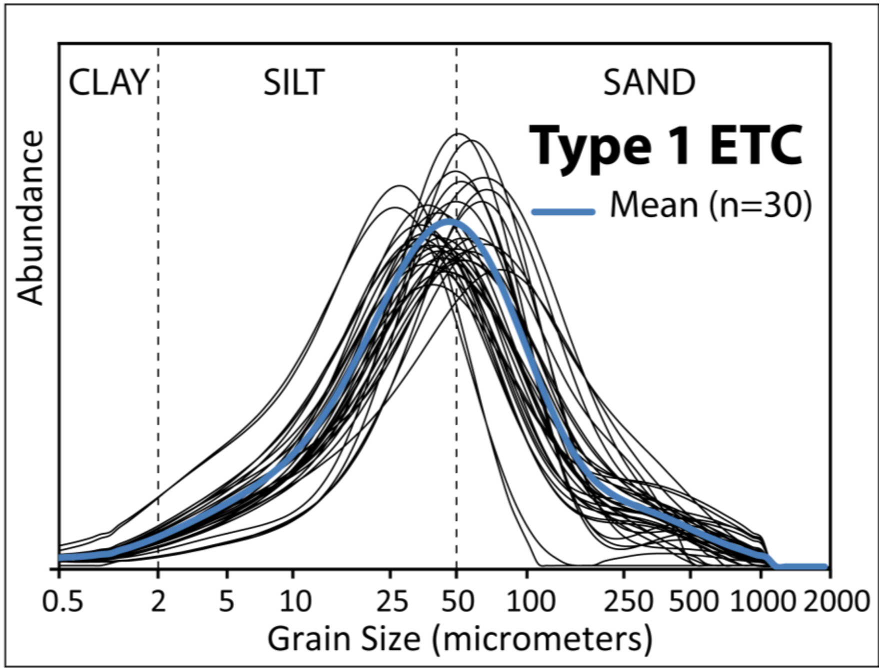


Figure 5.4: The continuous textural curves of the 30 samples assigned a type 1 ETC, with the blue line representing the mean textural curve. See Table 5.2 for more details.

Table 5.2: Characteristics of type 1 eolian textural curves.

Type 1 ETC (n=30)	Loess thickness	Modal particle size	Fine silt (12-25 µm)	Medium silt (25-35 µm)	Coarse silt (35-50 µm)	**Silt (2-50 µm)**	Fine very fine sand (50-75 µm)	**Medium sand (250-500 µm)**
	cm	*µm*	*Percentage clay-free*					
Min.	20.0	27.8	10.0	8.3	11.3	**34.5**	11.5	**0.0**
Max.	95.0	78.5	34.7	19.9	18.2	**84.7**	22.0	**8.3**
Mean	40.0	48.7	18.1	13.0	15.6	**53.8**	16.7	**4.1**
Standard Deviation	15.2	12.1	5.7	3.0	1.6	**11.4**	2.3	**1.8**

5.2.1.2 Type 2: Bimodal Silt Curves

Type 2 eolian textural curves are the most common textural curve type within the broad study area (n = 122) (Table 5.3). These samples have less total clay-free silt than type 1 samples. Type 2 samples have a mean clay-free silt percentage of ~ 48 percent, whereas type 1 samples have a mean of ~ 54 percent (Tables 5.2 and 5.3). Most importantly, type 2 ETC samples have a bimodal continuous textural curve, whereas type 1 samples generally have a unimodal textural curve (Figures 5.4 and 5.5). Type 2 samples have a dominant modal particle size in the very coarse silt fraction (35-50 µm), similar to type 1 samples, but they also have a secondary peak, usually in the medium sand fraction (250-500 µm) (Figure 5.5). Therefore, the main attribute that separates type 2 from type 1 samples is the presence of a second mode. Because the second mode is in a sand fraction, type 2 samples have an overall higher percentage of sand compared to type 1 samples. For example, the type 2 samples have a mean clay-free medium sand percentage of ~ 10, whereas type 1 samples have a mean of ~ 4 percent clay-free medium sand (Table 5.3). However, there is no notable difference in loess thickness between these two curve types; both type 1 and 2 ETC sites have a mean loess thickness of ~ 40 cm (Tables 5.2; 5.3).

The distinct bimodality of particle size distributions of type 2 samples, as shown in Figures 5.5 and 5.6, almost certainly resulted from the admixture of coarse sands from below the loess deposit, into the loess proper. The coarser sediments from the underling glacial drift have presumably been mixed with the loess through various forms of bioturbation and frost action (Schaetzl and Hook 2008). For example, soil infauna such as ants, termites, earthworms, badgers, gophers and moles burrow in the soil as a means of finding food and providing shelter for hibernation or reproduction (Thorp 1949; Hole 1981; Carpenter 1953; Van Nest 2002). These infauna species often move soil sediments within a soil profile, as a result of burrowing and ingesting soil particles (Thorp 1949; Hole 1981; Tyler et al. 2001). Many soils that lack discrete horizon boundaries often owe their morphologies to long-term mixing of their upper layers by infauna, especially worms and ants (Langmaid 1964). Within the broad study area, where loess deposits are thin and where the lithologic discontinuity to the underlying sediment is well within the soil profile, infauna bioturbation is likely the main process that mixes the underlying sediments into the loess deposits.

In the field, at a small number of sites, samples were recovered from both the loess and the underlying sediment in order to provide more detail about the sediments below the lithologic discontinuity. As an example, at sample site 870, one textural sample was taken from the identified loess deposit and another sample from below the loess. Figure 5.5 compares the continuous textural curves of the loess deposit and sediment below. The loess sample (which is a composite sample of the entire loess column) exhibits a dominant mode within the 25-50 µm fraction, and a second peak in the 250-500 µm fraction, i.e., a type 2 ETC. However, the sample at depth, in the drift, is unimodal, with a very low abundance of silt, and a mode within the 250-500 µm fraction (Figure 5.5). The mode of the deep sample is roughly at the same location along the size fraction as the secondary mode of the loess sample, ranging from 250 to 500 µm. Thus, the secondary mode in the loess sample is likely attributed to in-mixing of underlying sands into the loess, either during loess deposition or by pedoturbation processes, e.g., bioturbation, cryoturbation, that occurred later or during soil development.

Data in Figures 5.5 and 5.6 suggest that the original loess was much siltier and had less sand than at present, perhaps like the type 1 ETCs shown in Figure 5.4. The relatively uniform particle-size distributions within the silt fractions also supports this conclusion, i.e., the mean contents of the 12-25 µm fraction, 25-35 µm fraction, and 35-50 µm fraction (17.3, 11.6, and 13.1 percent, respectively) are relatively similar for type 2 samples. Likewise, type 1 samples have relatively the same uniform particle-size distributions within the same silt-size fractions, with the mean contents being 19.0, 13.0, and 15.6 percent, respectively. In addition the mode of the sample at depth is within the 250-500 µm fraction, which is the same size fraction as the secondary mode of the type 2 loess deposits (Figure 5.6). Therefore, because type 2 samples have a mode within the 25-75 µm fraction, similar to type 1 samples, this research suggest this 25-75 µm fraction likely originated as loess. Conversely, particles within the 250-500 µm fraction likely did not originate as loess, but instead originated as glacial till or outwash, due to their sediment size.

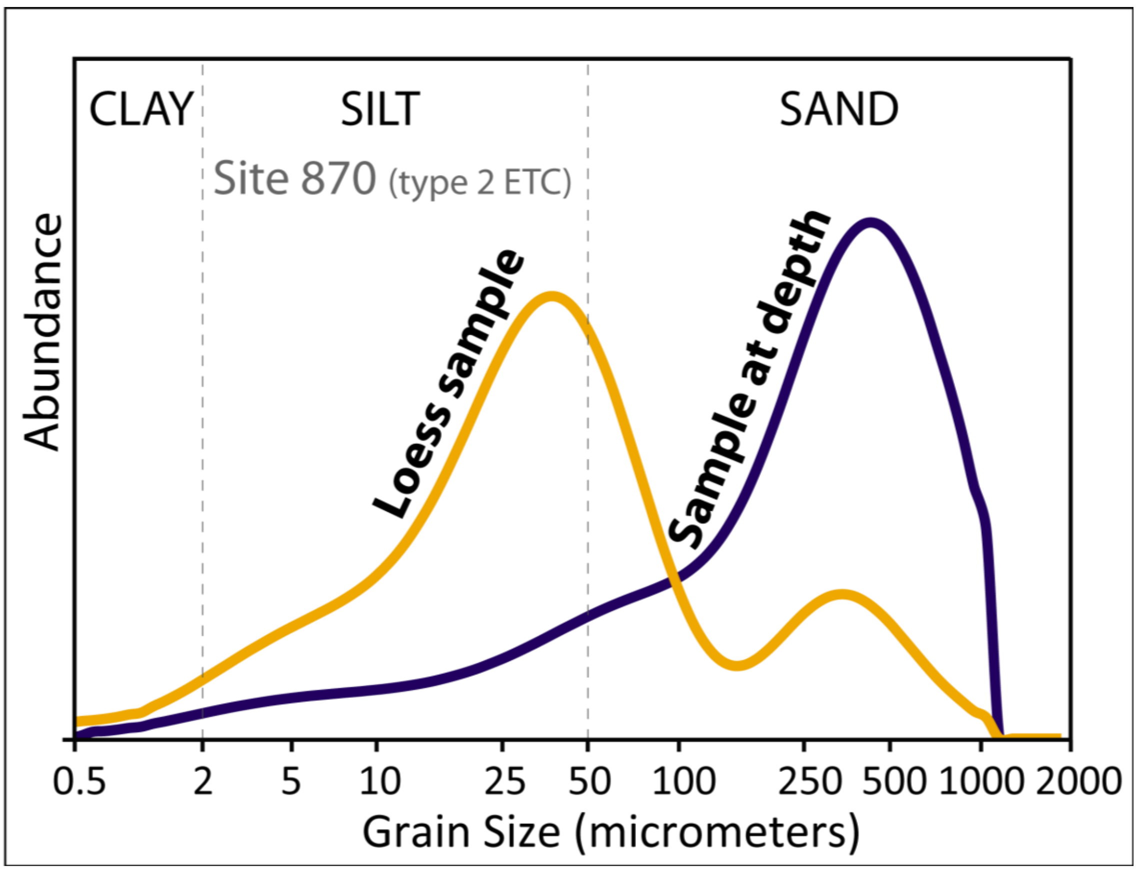


Figure 5.5: The continuous textural curves of two samples taken from site 870; the yellow line showing the continuous textural curve of the loess and blue showing the sample's continuous texture at depth.

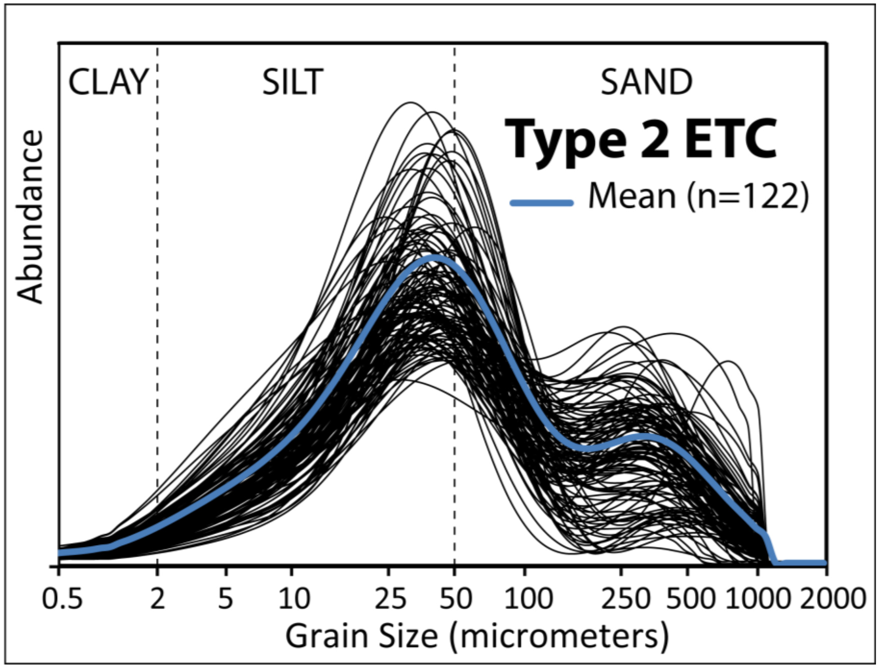


Figure 5.6: The continuous textural curves of the samples assigned a type 2 ETC, with the blue line representing the mean textural curve. See Table 5.3 for more details.

Table 5.3: Characteristics of type 2 samples.

Type 2 ETC (n=122)	Loess thickness	Modal particle size	Fine silt (12-25 µm)	Medium silt (25-35 µm)	Coarse silt (35-50 µm)	**Silt (2-50 µm)**	Fine very fine sand (50-75 µm)	**Medium sand (250-500 µm)**
	cm	*µm*	*Percentage clay-free*					
Min.	20.0	25.5	7.2	7.4	8.9	**32.0**	9.0	**1.9**
Max.	85.0	74.6	34.3	17.4	19.7	**79.3**	22.1	**18.0**
Mean	40.6	41.5	17.3	11.6	13.1	**48.8**	13.2	**10.3**
Standard Deviation	13.4	7.6	4.3	2.1	2.5	**8.8**	2.6	**4.0**

5.2.1.3 Type 3: Bimodal Sand Curves

A total of 28 samples were assigned a type 3 eolian textural curve; these samples, like type 2 ETCs, have a bimodal continuous textural curve. Type 3 samples have a mean clay-free silt percentage of ~ 31 percent, and have a mode in the very coarse silt fraction (~ 54 µm). However, type 3 samples are different from type 2 samples, because their dominant mode, or larger peak is in the sand fraction (mean of ~ 280 µm), as opposed to the silt fraction, like type 1 and 2 textural curves. Thus, type 3 samples appear to represent mainly sandy sediment with varying degrees of silt admixture, as opposed to type 2 samples, which appear to be silty sediment with sandy admixtures (Figures 5.6 and 5.7). Type 3 samples have a mean clay-free medium sand content of ~ 20 percent, whereas types 1 and 2 samples have a mean of ~ 10 percent and ~ 4 percent (Tables 5.2, 5.3 and 5.4). Type 3 ETC sites also had a thinner mean loess thickness (~ 33 cm) compared to ETC type sites 1 and 2 (~ 40 cm), which could help explain their higher sand content percentages (Tables 5.2, 5.3 and 5.4). The thinner loess deposits generally have a smaller amount of silty sediment available for mixing into the initial sandy sediment, than do the thicker loess deposits. The large sand mode in type 3 samples is typically between 250 and 500µm and is larger than their silt mode. At these sites, the loess deposits are likely thin enough that they have been thoroughly mixed into the sandy outwash below, as is shown on the particle size curves by a small, secondary mode within the silt fraction (Figure 5.7).

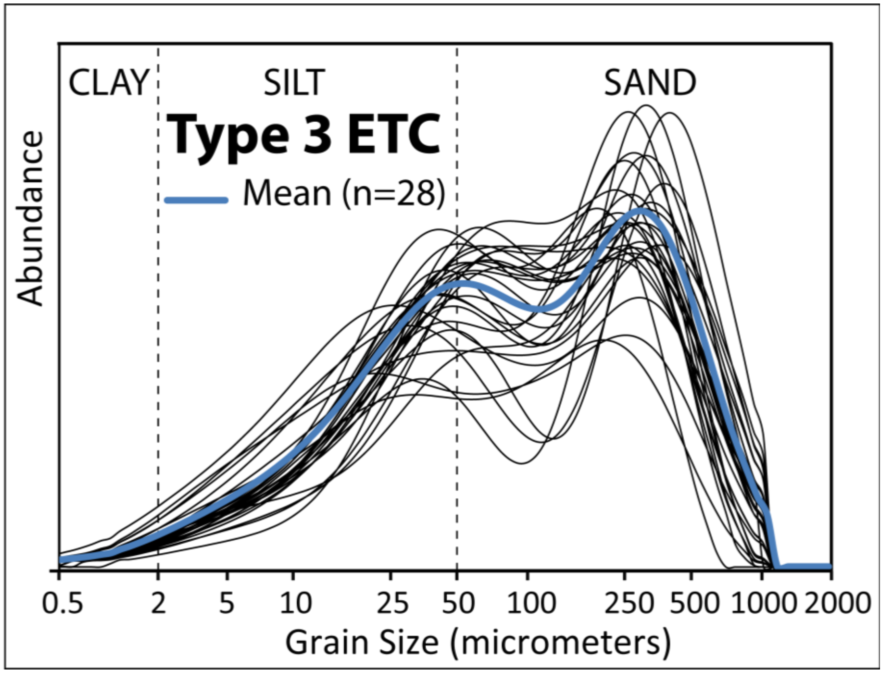


Figure 5.7: The continuous textural curves of the samples assigned a type 3 ETC, with the blue line representing the mean textural curve. See Table 5.4 for more details.

Table 5.4: Characteristics of type 3 samples.

Type 3 ETC (n=28)	Loess thickness	Modal particle size	Fine silt (12-25 µm)	Medium silt (25-35 µm)	Coarse silt (35-50 µm)	**Silt (2-50 µm)**	Fine very fine sand (50-75 µm)	**Medium sand (250-500 µm)**
	cm	*µm*	*Percentage clay-free*					
Min.	0.0	27.7	5.6	5.4	6.6	**22.0**	6.4	**14.7**
Max.	80.0	415.3	23.0	9.2	10.6	**43.8**	11.8	**30.0**
Mean	32.5	280.5	14.2	7.1	8.5	**30.6**	9.8	**20.1**
Standard Deviation	14.9	80.3	4.5	0.9	0.8	**5.1**	1.4	**3.2**

5.2.1.4 Type 4: Silt Shoulder Curves

The type 4 eolian textural curve is the second most common continuous textural curve type within the broad study area (n=68). Type 4 samples are a hybrid between a type 1 (unimodal silt curve) and a type 2 (bimodal silt curve). Type 4 samples have a unimodal continuous textural curve with the modal particle size in the 25-75 µm fraction, thus, resembling a type 1 sample (Figures 5.4 and 5.8). However, similar to type 2 and 3 samples, type 4 samples have more sand than do type 1 samples. Type 4 samples are comparable to type 2 samples with both having a mode within the 25-75 µm fraction and an increase in abundance within the 250-500 µm fraction. The difference between the type 4 and 2 samples is the amount of sand; type 4 samples have a shoulder curve within the 250-500 µm fraction, and thus usually have less sand contents compared to the type 2 samples, which have a “true” secondary mode within the 250-500 µm fraction (Figures 5.6 and 5.8). For this reason, type 4 ETCs are described as having a silt *shoulder* curve – a silt mode but a shoulder in the sand fraction.

Type 4 samples are unimodal in the 25-75 µm fraction with a change in slope usually near the 125 µm fraction where the gradient of the line changes from a steep negative slope, to a more gradual/gentle slope throughout the 250-500 µm fraction (Figure 5.8). Sun et al. (2004) described a shoulder curve as a “S curve” when analyzing continuous textural curves. Type 4 samples have a mean total clay-free silt content of ~ 46 percent, but as expressed in their shoulder curve, they also have a mean clay-free medium sand content of ~ 9 percent (Table 5.4). Type 4 sample sites have a mean loess thickness of ~ 34 cm, which is similar to type 3 sample sites (mean of ~ 33 cm), but type 4 sites exhibit thinner loess than both type 1 and 2 sites (mean of ~ 40 cm) (Tables 5.2, 5.3, 5.4 and 5.5).

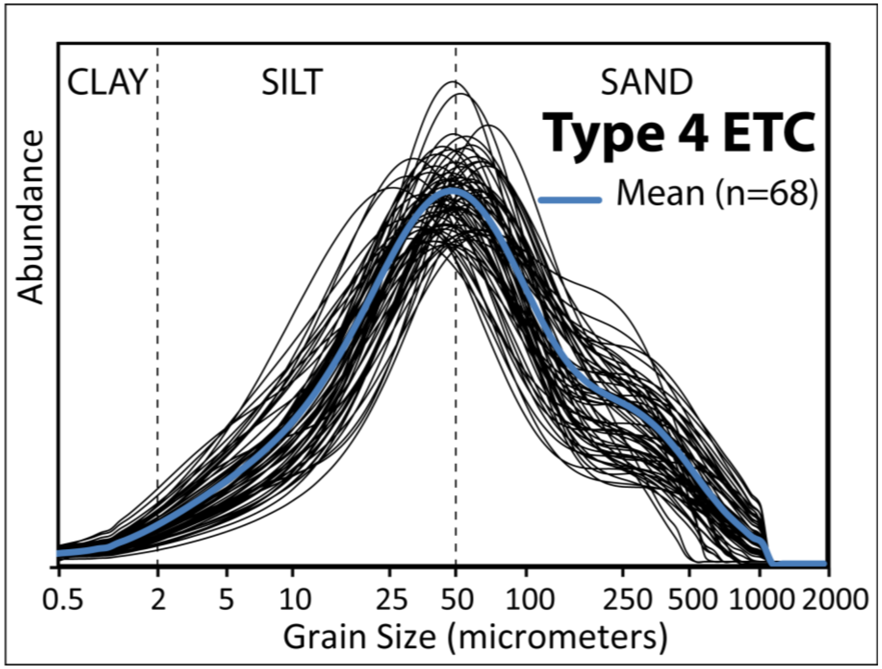


Figure 5.8: The continuous textural curves of the samples assigned a type 4 ETC, with the blue line representing the mean textural curve. See Table 5.5 for more details.

Table 5.5: Characteristics of type 4 samples.

Type 4 ETC (n=68)	Loess thickness	Modal particle size	Fine silt (12-25 µm)	Medium silt (25-35 µm)	Coarse silt (35-50 µm)	**Silt (2-50 µm)**	Fine very fine sand (50-75 µm)	**Medium sand (250-500 µm)**
	cm	*µm*	*Percentage clay-free*					
Min.	20	27.4	7.5	7.1	9.2	**29.6**	10.6	**4.6**
Max.	63	79.1	27.3	14.9	16.5	**65.3**	18.6	**16.1**
Mean	34.4	51.0	16.1	10.8	12.9	**45.7**	14.4	**9.0**
Standard Deviation	11.2	12.1	5.3	1.9	1.6	**8.5**	1.7	**2.6**

Sample site 1086 is another location within the broad study area where samples were collected from both the identified loess deposit and the subjacent sediment below the loess. Figure 5.9 compares the continuous textural curves of the loess deposit with the sediment below. The loess sample has a mode within the 25-75 µm fraction and a *shoulder* near the 250-500 µm fraction (thus, it has a type 4 ETC), whereas the sample at depth is unimodal, with a low abundance of silt and a mode within the 250-500 µm fraction (Figure 5.9). These curves suggest that type 4 samples may have originally been much siltier, but have been mixed with the coarser underlying parent material, similar to type 2 samples, but the process has not occurred to as great an extent.

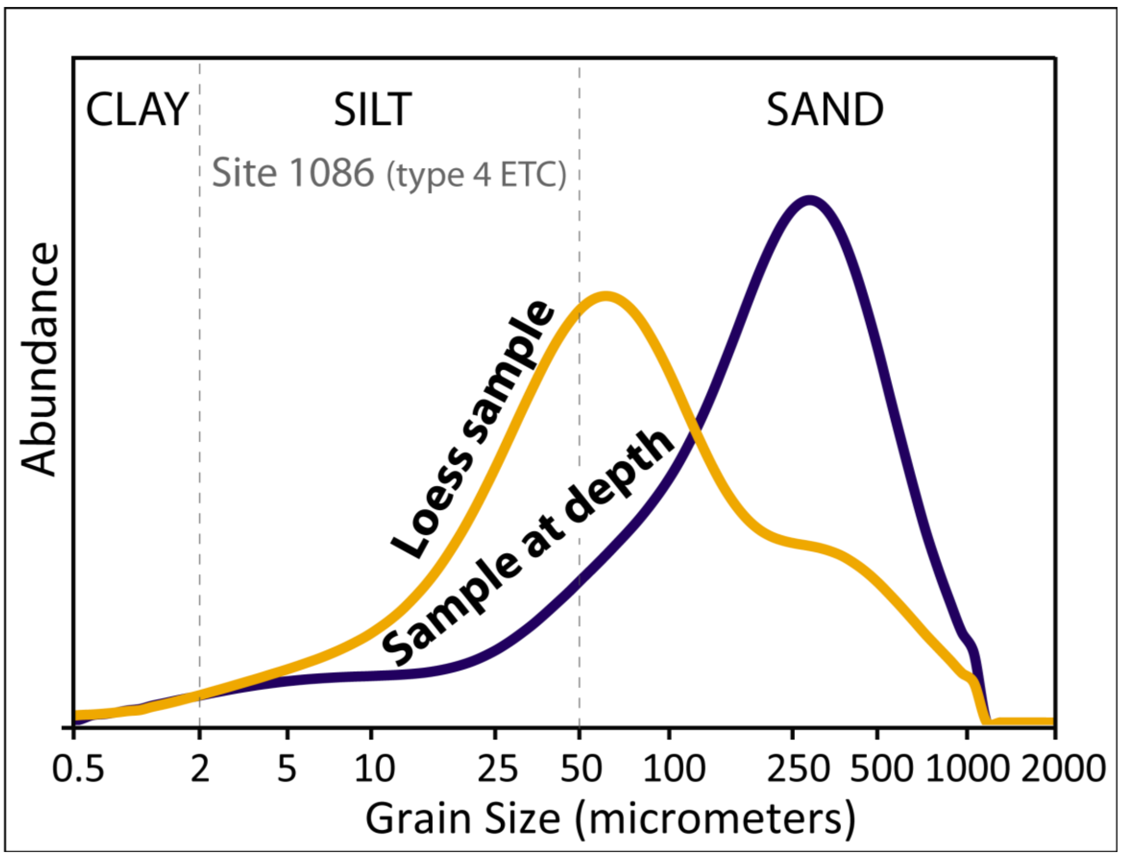


Figure 5.9: The continuous textural curves of two samples taken from site 1086; the yellow line is the continuous textural curve of the loess and blue is the continuous textural curve for the sediment at depth.

5.2.1.5 Type 5: Sand Shoulder Curves

The type 5 eolian textural curve category is the least common textural curve within the broad study area (n=12). Similar to type 4 samples, type 5 sample have a unimodal *shoulder* curve, but are categorized differently because the sample's modal particle size is within the 250-500 µm fraction (medium sand). Type 5 samples do not have a true second mode the slope of the textural curve usually changes within the 25-75 µm fraction. Hence, these samples are described as having a *sand* shoulder curve (Figure 5.10). Type 5 textural curves exhibit a gradual and positive slope throughout the 25-75 µm fraction, documenting that these samples have an abundance of particles within the 25-75 µm fraction (Figure 5.10). Type 5 samples have a mean total clay-free silt content of ~ 26 percent, but they also have the highest percentage of total clay-free sand (mean of ~ 74 percent) (Table 5.6). The type 5 ETC sample sites have the smallest mean loess thickness (~ 28 cm). These thin loess deposits have likely experienced more mixing during and after loess deposition, than did the thicker loess deposits. Moreover, vectors for mixing the loess with the underlying parent material are likely more efficient in thinner loess deposits than in thicker loess deposits. Therefore, the continuous textural curves of type 5 samples show that these samples are dominantly sandy sediments with a low abundance of sediment from the 25-75 µm fraction.

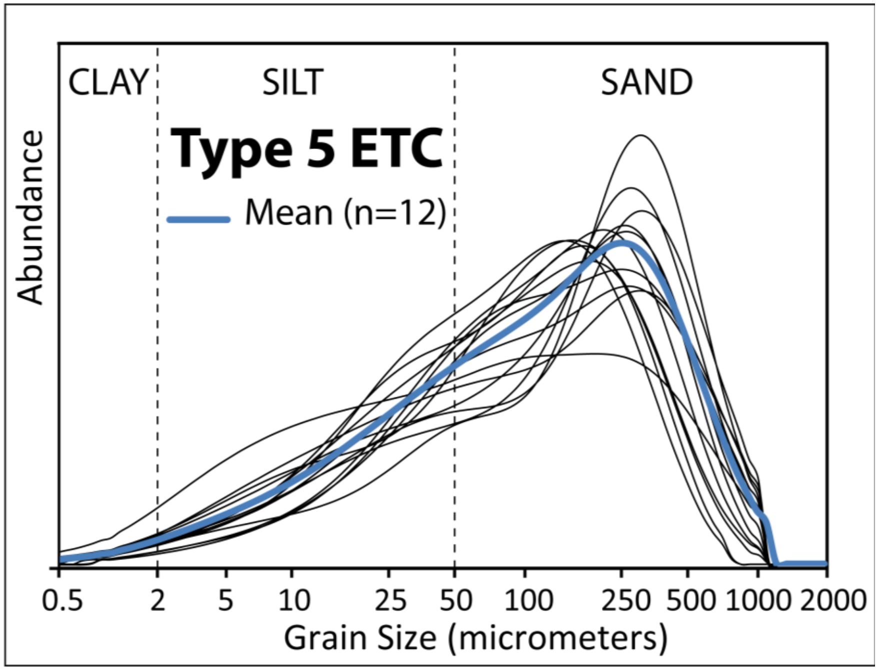


Figure 5.10: The continuous textural curves of the samples assigned a type 5 ETC, with the blue line representing the mean textural curve. See Table 5.6 for more details.

Table 5.6: Characteristics of type 5 samples.

Type 5 ETC (n=12)	Loess thickness	Modal particle size	Fine silt (12-25 µm)	Medium and Coarse silt (25-50 µm)	**Silt (2-50 µm)**	Fine sand (125-250 µm)	Medium sand (250-500 µm)	**Sand (50-2000 µm)**
	cm	*µm*	*Percent Clay-free*					
Min.	0.0	151.3	9.0	8.7	**16.5**	17.6	13.8	**65.0**
Max.	40.0	324.8	24.4	16.9	**35.0**	25.0	30.6	**83.5**
Mean	27.7	242.6	14.2	13.1	**26.0**	22.0	20.0	**74.0**
Standard Deviation	10.0	60.9	3.7	2.1	**5.2**	2.3	4.3	**5.2**

In summary, loess has various textural signatures throughout the broad study area. In this thesis, I have divided loess samples from the braod study area into five ETC categories. Nonetheless, there are two dominant eolian textural curve types:

(1) Those with high contents within the 25-75 µm fraction and a secondary peak (or shoulder) within the 250-500 µm fraction (types 1, 2 and 4)

(2) Those with high contents within the 250-500 µm fraction and a secondary peak (or shoulder) within the 25-75 µm faction (types 3 and 5).

Eolian textural curve types 1, 2, and 4 have a mean modal particle size within the 42-51 µm fraction (Figure 5.11). Conversely, eolian textural curve types 3 and 5 have a mean modal particle size within the 243-281 µm fraction (Figure 5.11).

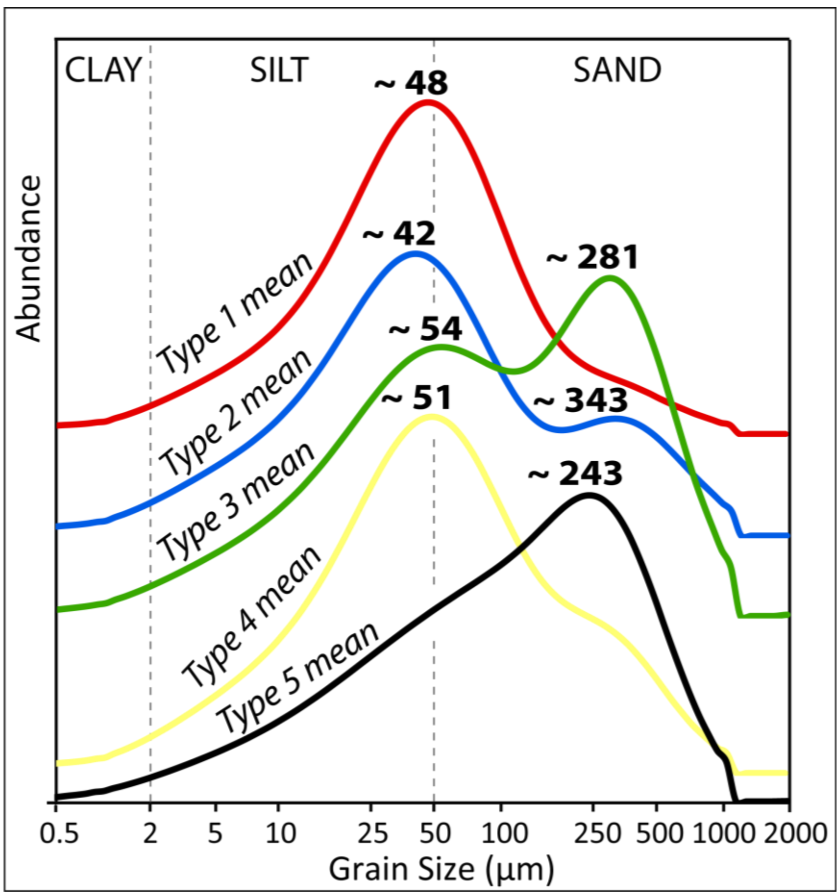


Figure 5.11: Summary diagram of the five ETC types and their mean continuous textual curves.

5.2.1.6 Distribution of Sites with Different Textural Curves

Maps of the spatial distribution of ETC types within the broad study area could potentially suggest a relationship between eolian textural type, loess thickness, and distance from presumed source area(s). Figure 5.12 shows the sample locations within the broad study area, with each sample labled by their assigned ETC type. It is immediately evident that the map lacks a promiant spatial trend with respect to ETC type, across the broad study area. However, there are a few noteworthy spatial trends of ETC type curves within smaller parts of the broad study area, e.g., there are small concentrations of type 1 samples in the center of the broad study area, particularly east of the Baraga Plains (Figures 5.12 and 5.13). Both type 2 and 4 ETCs (which have the second highest total silt contents) are mapped throughout the entire broad study area (Tables 5.3 and 5.5; Figure 5.12). Type 2 ETCs dominate the southern portion of the broad study area and comprise ~ 82 percent of the samples within Iron County (Figures 5.12 and 5.13), whereas type 4 samples are mostly located in Baraga and Marquette Counties. Lastly, both type 5 and type 3 samples, which have high sand contents and low silt contents, are mainly mapped in the high-relief and northern regions of the broad study area; all type 5 samples (unimodal sand shoulder curve) are mapped within the high-relief Peshekee Highlands (Figures 5.12 and 5.13). Figure 5.14 shows the distribution of samples with high silt contents (roughly the 25-75 µm fraction) vs. those with high sand contents (roughly the 150-500 µm fraction).

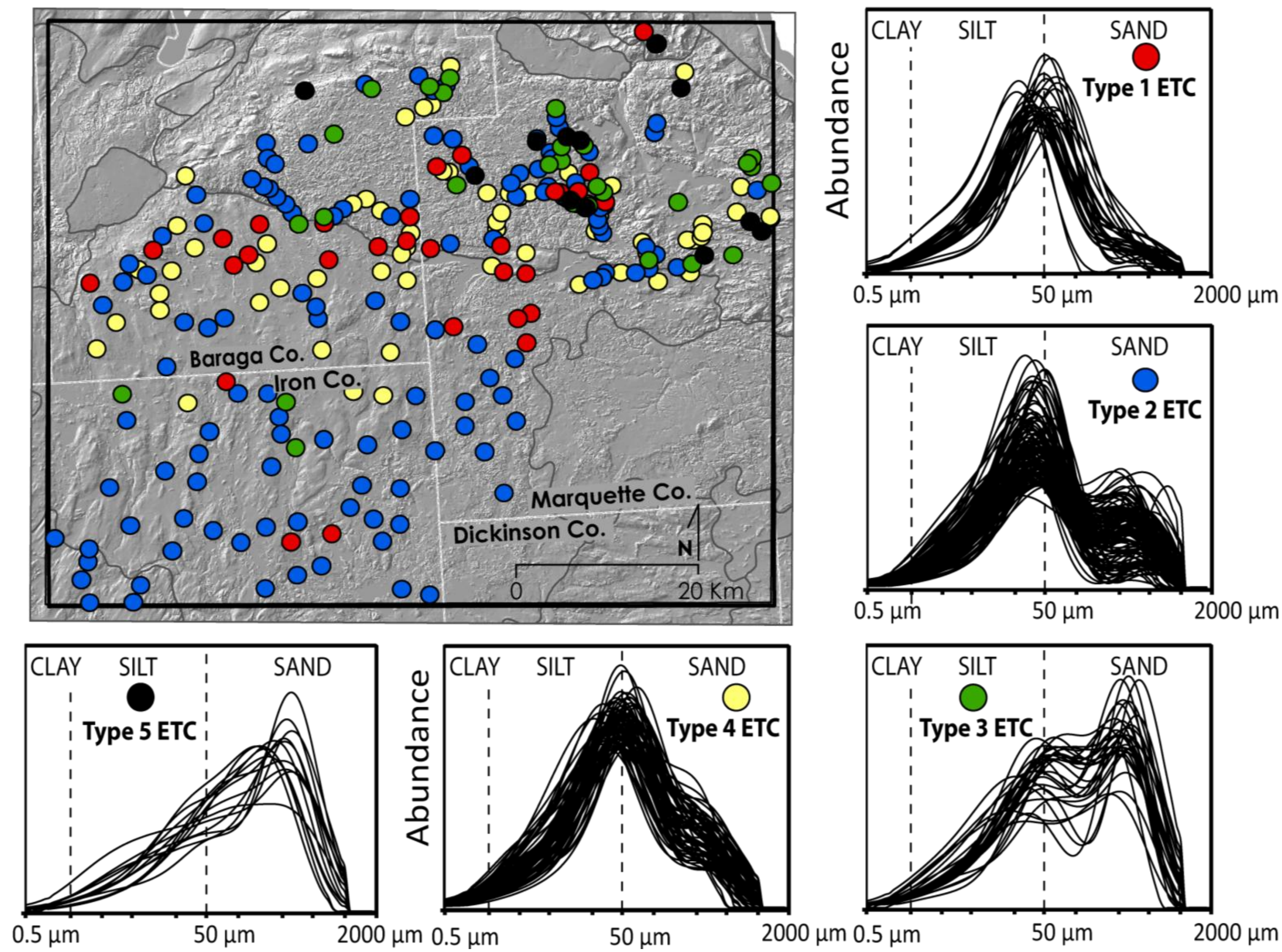


Figure 5.12: The distribution of soil (loess) samples taken within the broad study area, symbolized by their eolian textural curve type.

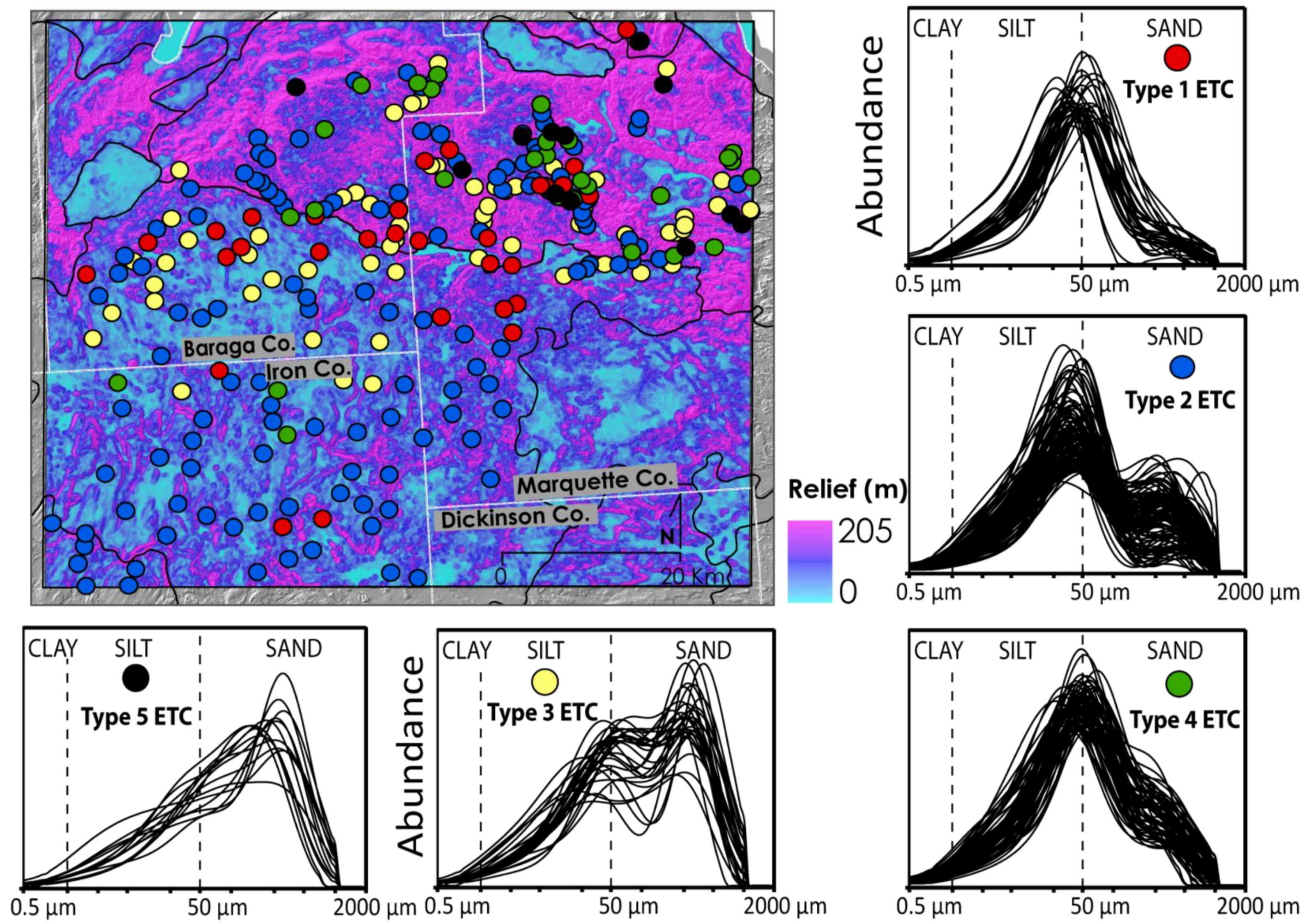


Figure 5.13: The distribution of ETC types plotted against a background of local relief, within the broad study area.

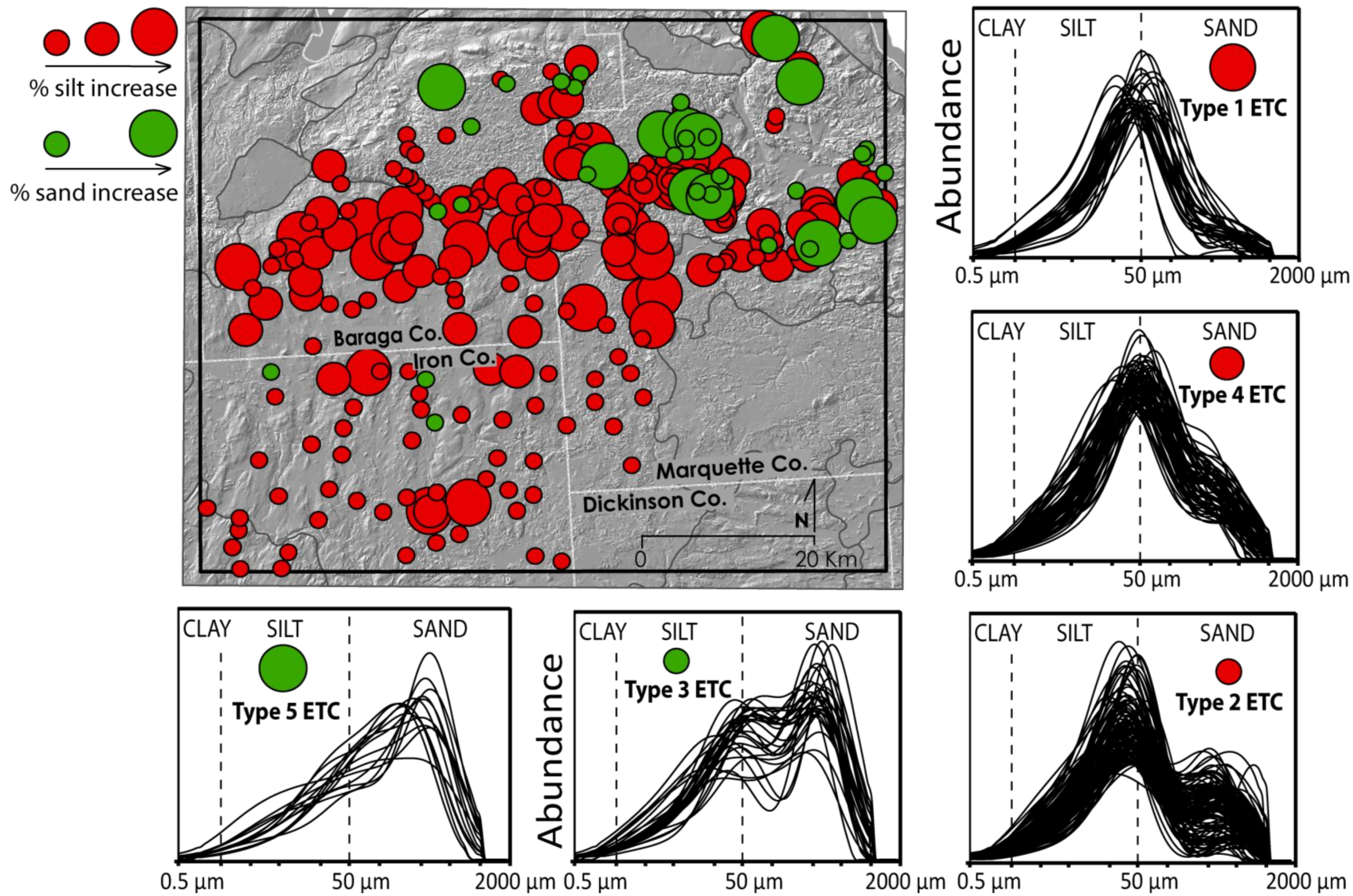


Figure 5.14: The distribution of eolian textural type curves with generally high silt contents and low sand contents (labeled in red), and high sand contents and low silt contents (labeled in green).

Eolian textural curve types with high silt contents (types 1, 2, and 4) are representative of ~ 85 percent of the sites within the broad study area (Figure 5.14). This finding confirms that loess is widespread across the broad study area, and validates the NRCS soil survey data and the conclusions of Scull and Schaetzl (2011). Although samples with high silt contents are located across the entire, broad study area, they particularly dominate the southern and western regions (Figure 5.14). Conversely, samples with high sand contents (types 3 and 5) are uncommon (comprising ~ 15 percent of the sites) and are mainly mapped in the northeastern regions of the broad study area (Figure 5.14). Figure 5.15 shows that ~ 88 percent of the “high sand” samples (types 3 and 5) are located within the high-relief Peshekee Highlands. The high sand content samples have a mean loess thickness of ~ 30 ± 13.8 cm, whereas the high silt content sample sites have a mean loess thickness of ~ 38 cm (Tables 5.2, 5.3, 5.4, 5.5 and 5.6). Using a t-test (assuming unequal variances), the loess thicknesses associated with high silt and high sand content groups were significantly different at $P < 0.001$.

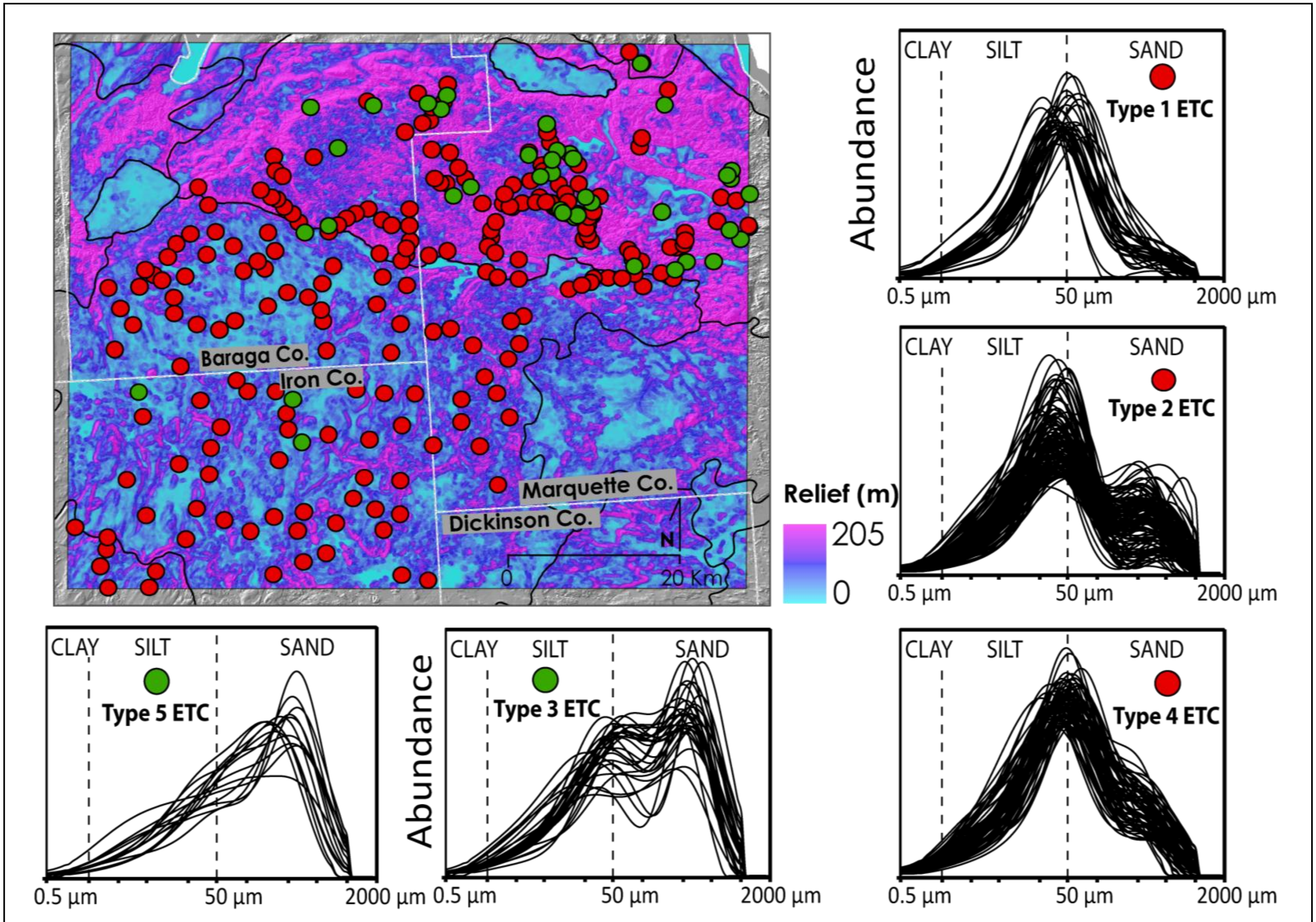


Figure 5.15: The distribution of eolian textural type curves with high silt and high sand contents, plotted against relief within the broad study area.

In summary, type 1 samples are the siltiest (with a mean of ~ 54 percent within the 25-75 µm fraction) and are located on sites with the thickest loess (a mean loess thickness of ~ 40 cm). The most prevalent textural curve type sampled within the broad study area is type 2 (bimodal, with a dominant mode within the 25-75 µm fraction). Second most common is the type 4 ETC. Like the type 2 samples, the modal particle size of the type 4 samples is within the 25-75 fraction with a second peak or shoulder within the 250-500 µm fraction. Eolian textural curve types 3 and 5 are not as common, which could be due to the field sampling procedure or a bias in field hand-texturing. For example, I generally avoided sites that had a surface texture similar to ETC types 3 and 5 because it was difficult to determine whether or not a site/sample had a bimodal texture in the field. Figure 5.15 shows that ETC types 3 and 5 are dominantly mapped within the high-relief Peshekee Highlands and Tables 5.3, 5.4, 5.5, and 5.6 show that these loess deposits are generally thinner (mean of ~ 30 cm). Where loess depositional events were short-lived, original surface sediments were likely being mixed during loess deposition. Moreover, after deposition, where loess deposits are thinner, vectors for mixing underlying sediments with the loess, such as bioturbation and cryoturbation, are likely more efficient than in thicker loess deposits. Thus, in the northern regions of the broad study area where loess deposits are typically thinner, it is more common for loess samples to be dominantly sandy (Figure 5.15).

5.3 Spatial Characteristics of Loess within the Study Area

In the past, loess deposits have been associated with a wedge-shape, with both loess thickness and particle size decreasing from the loess source (Smith 1942; Ruhe 1954; Frazee et al. 1970; Olson and Ruhe 1979; Muhs and Bettis 2000). This section will examine the spatial characteristics of loess within the study area - defined by the extent of the loess sample points - and determine whether the loess characteristics are similar to the spatial trends of thicker loess deposits in the Great Lakes Region. I will first focus on three traditional characteristics of loess by showing and discussing interpolated maps of (1) loess thickness, (2) silt distribution, and (3) sand distribution. Then, because many of the loess deposits within the study area are comprised of two particle size fractions; 25-75 µm fraction and the 250-500 µm fraction, maps of these fractions will be discussed.

5.3.1 Loess Thickness Data

Within the study area sampled sites exhibited loess thicknesses that ranged between approximately 80 and 20 cm (Figure 5.16). Loess is generally thickest (> 80 cm thick) in southern and southwestern Iron County. It progressively thins towards northeastern Marquette County, where loess deposits are commonly < 20 cm thick (Figure 5.16). This thickness range is similar to reports of loess thicknesses in the western Upper Peninsula by Scull and Schaetzl (2011) and Bigsby (2010). The interpolated loess thickness trend (Figure 5.16) also matches well with the loess thicknesses produced using NRCS soils data (Figure 3.12). However, anomalously thick areas of loess, not before documented, do occur in the western and north-central regions of the study area. For example, east of the Baraga Plains, loess is estimated to be between 48 and 58 cm thick, compared to the surrounding area where loess thicknesses are estimated to be between 33 and 36 cm (Figure 5.16). Similarly, in the north-central region of the study area, near the Peshekee River, there is a small area of loess estimated to range between 48 and 58 cm in thickness, whereas loess deposits in the surrounding areas are generally between 12 and 21 cm (Figure 5.16). Schaetzl and Liebens (1992, 1993) reported on the thick loess near the Peshekee River, although this work was never published. With the exception of a few anomalously thick areas, the loess deposits within the study area generally exhibits a wedge-shaped thickness trend (Figure 6.16), with the thickest loess in the south, and thinning towards the north. This trend is consistent with Midwestern loess literature (Smith 1942; Olson and Ruhe 1979; Muhs and Bettis 2000; Schaetzl and Hook 2008).

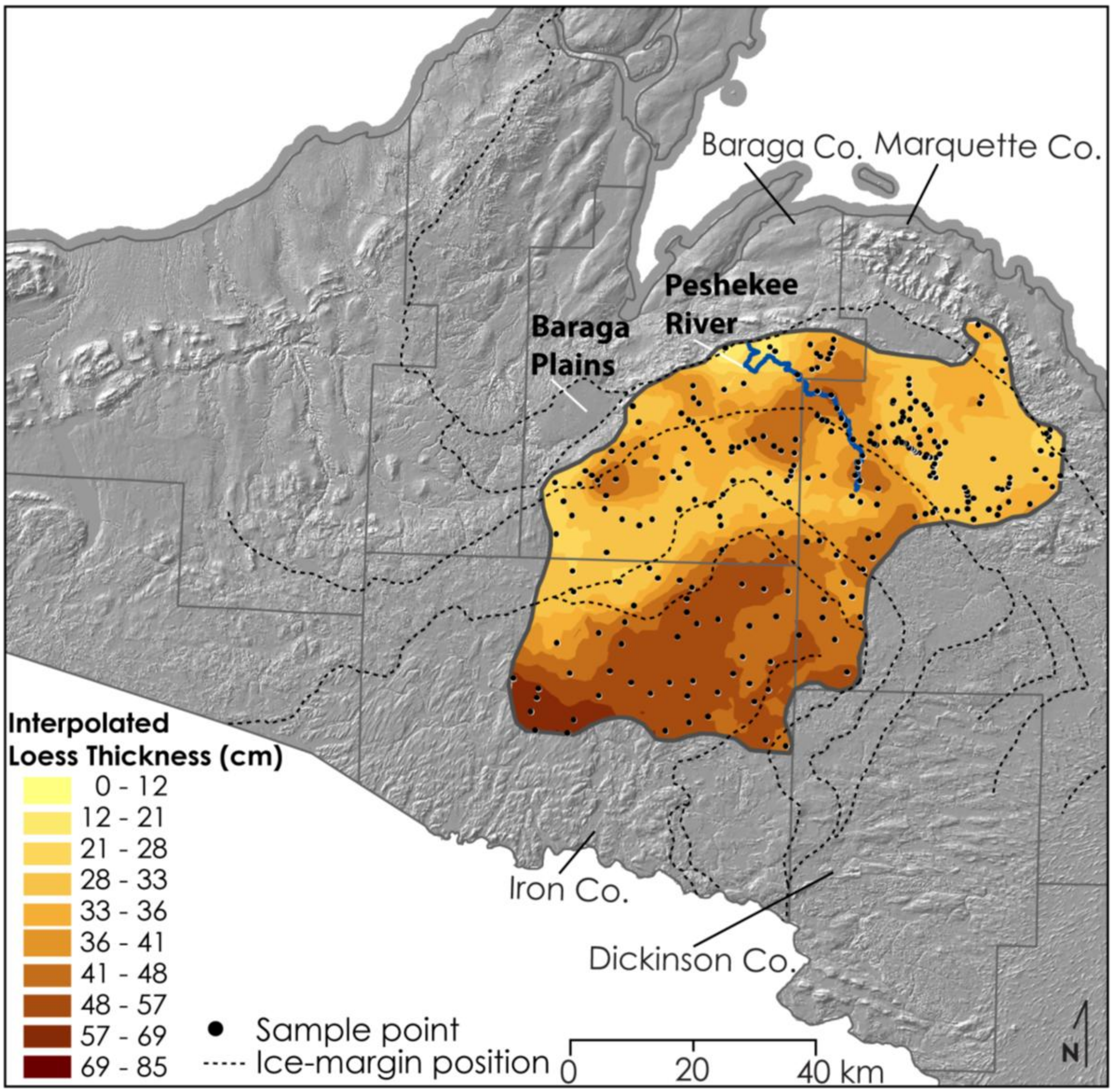


Figure 5.16: Interpolated loess thickness map for the study area.

5.3.2 Particle Size Analysis of the Peshekee Loess

5.3.2.1 Spatial Trend in Silt Contents

Samples with the highest total clay-free silt contents (2-50 µm fraction) generally occur in two regions of the study area: (1) in central Iron County, near the southern limits of the study area, and (2) in southern Baraga County, in the central and western regions of the study area (Figure 5.17). The distribution of clay-free *fine* silt (2-25 µm) has a similar spatial trend as the distribution of total silt contents, with the highest percentages occurring in the southern, central and western regions of the study area (Figure 5.18). The spatial distribution of silt contents changes, however, when mapping the distribution of clay-free *medium* silt (25-35 µm fraction) and *coarse* silt (35-50 µm fraction) (Figures 5.19 and 5.20). Figure 5.19 shows that the southern, central, and western regions of the study area have the highest percentages (~ 20) of medium silt, whereas Figure 5.20 illustrates that the southeastern regions of the study area (in western Marquette County) has the highest percentages (~20) of *coarse* silt. The spatial distribution of medium silt is a hybrid between the distribution of fine silt and coarse silt.

The loess surface texture map (Figure 3.11), created using NRCS data, matches well with the distribution of silt contents in the southern regions of the study area – that is, loessal soils here are dominantly being mapped with soils that have a silt loam surface texture, e.g., the Goodman and Wabeno soil series. The NRCS loess surface texture map also shows that sandier loessal soils (e.g. Keewaydin series) are usually mapped in the eastern regions of the study area; this parallels the higher coarse silt percentages that occur on the eastern regions of the study area (Figure 5.20). Conversely, the increased siltiness of the loessal soils in southern Baraga County and directly east of the Baraga Plains is not as evident from the NRCS surface texture map, as these loessal soils are mainly mapped as Champion which has a cobbly silt loam surface texture

(Figures 3.11 and 5.17). Champion soils are widely mapped throughout the region, even in areas that do not have a cobbly silt loam surface texture.

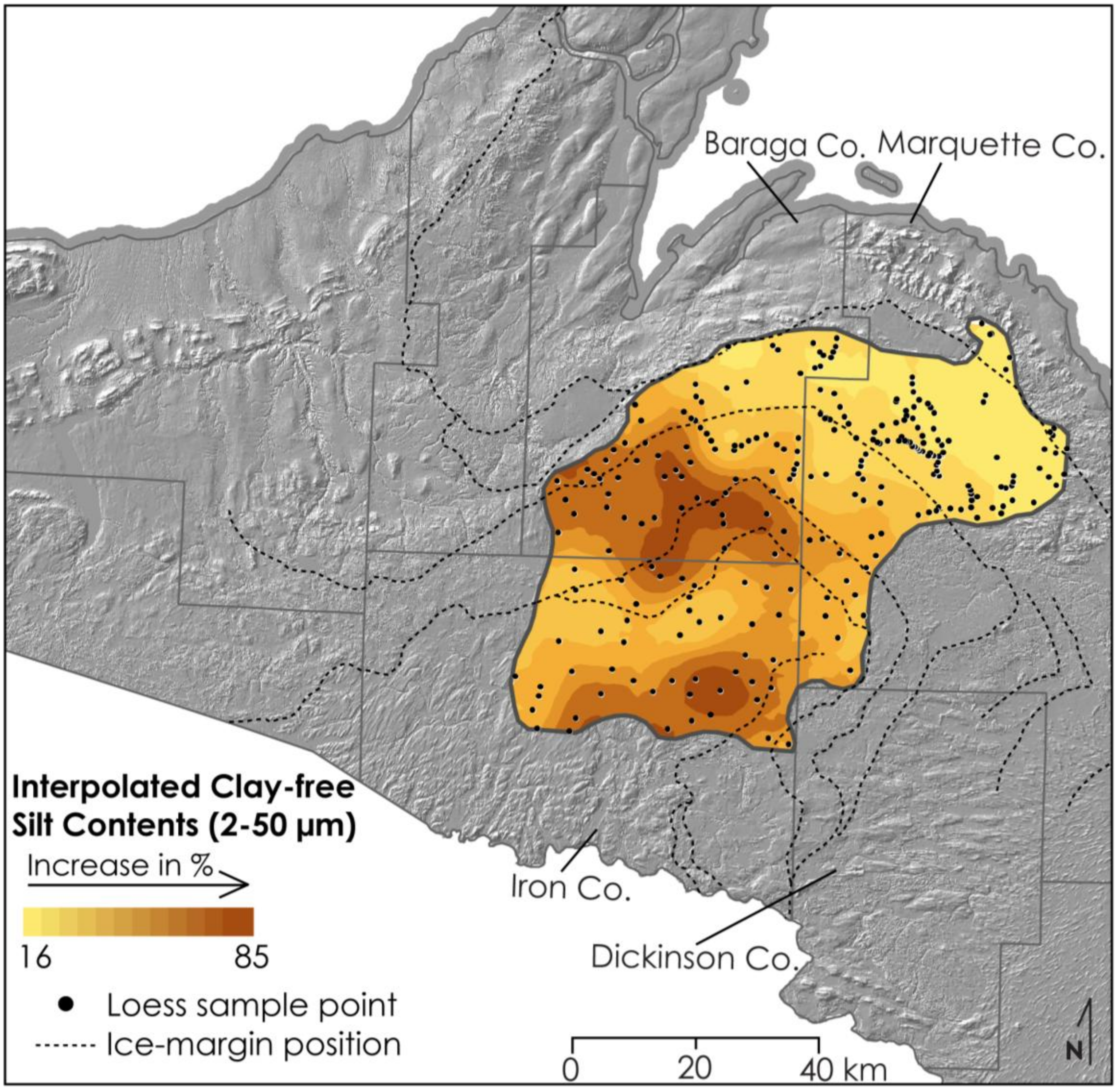


Figure 5.17: Interpolated map of clay-free silt contents in the study area.

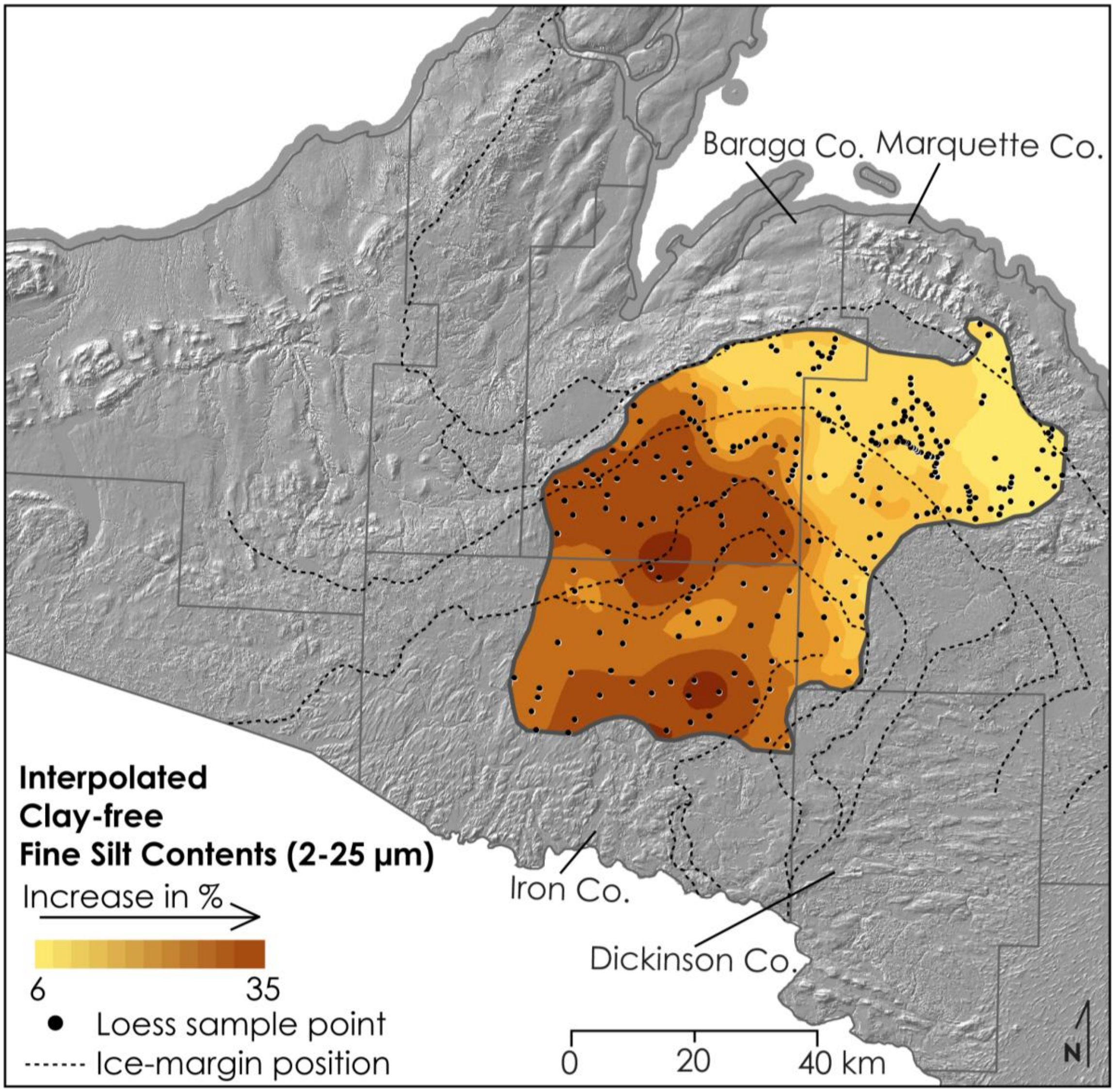


Figure 5.18: Interpolated map of clay-free fine silt contents in the study area.

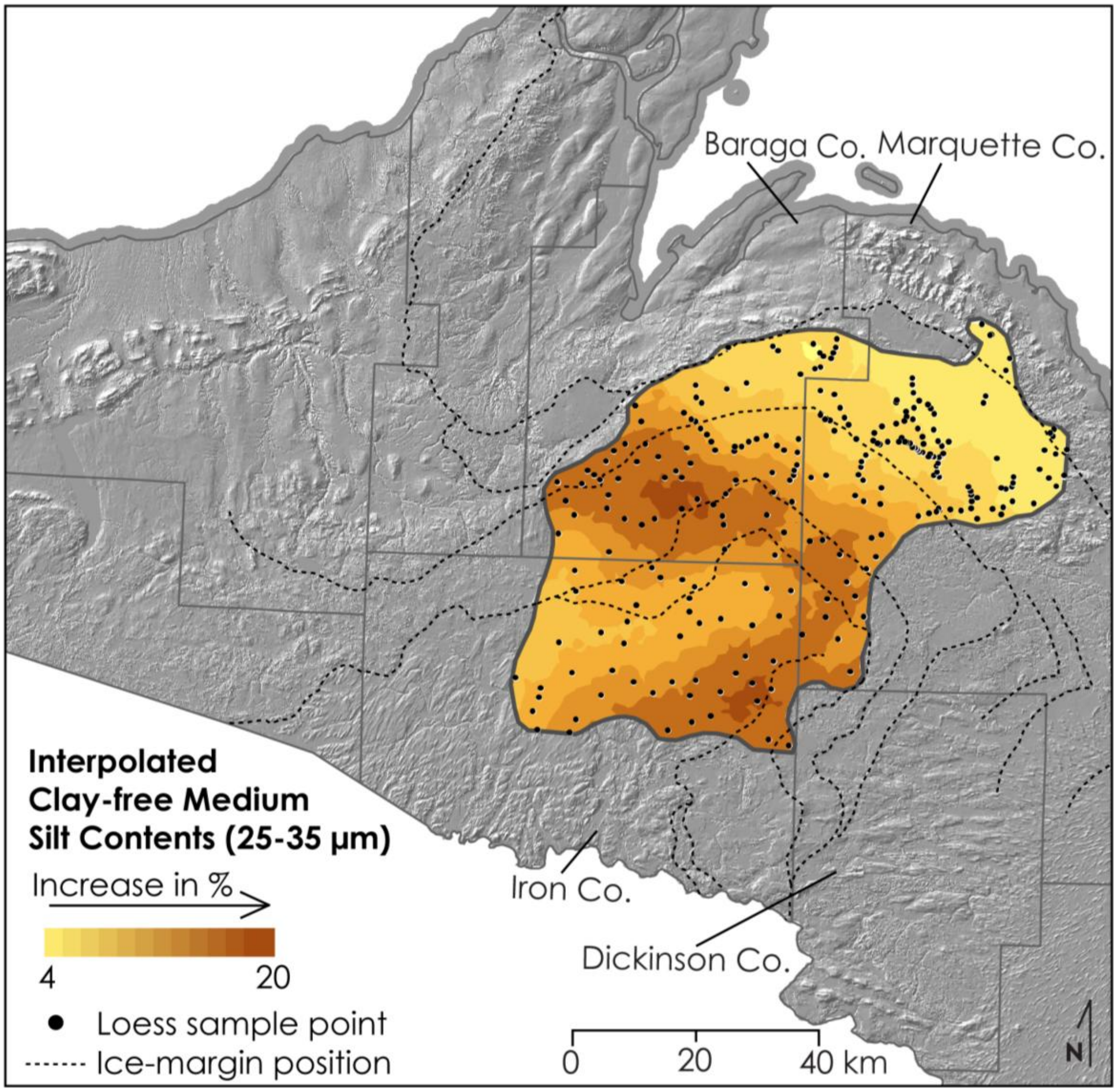


Figure 5.19: Interpolated map of clay-free medium silt contents in the study area.

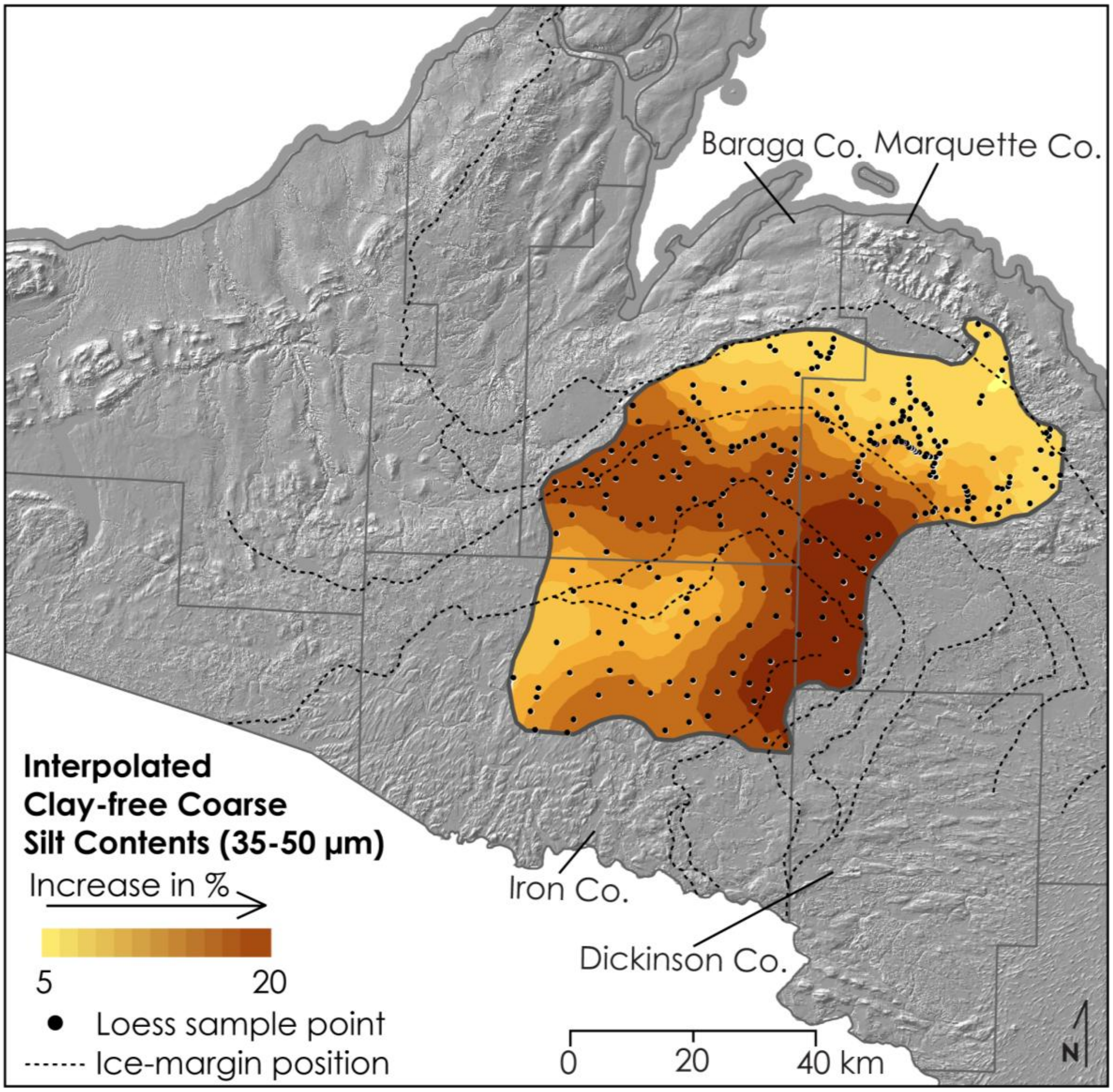


Figure 5.20: Interpolated map showing the distribution of clay-free coarse silt contents.

The loessal soils in eastern Baraga County are mainly mapped within the Champion, Michigamme, Petticoat, and Dishno series, all of which have cobbly silt loam surface textures. The interpolated loess thickness map suggests that loess deposits in eastern Baraga County tend to be thinner compared to northern Iron County or the southern regions of the study area (Figure 5.16). In periglacial environments, where soils are exposed to intense frost action, coarse fragments are often pushed or pulled to the surface (Corte 1963; Inglis 1965). The term upfreezing is used when water in soils expands as it freezes, and ice lenses develop under clasts within the soils. Thus, the soils expand when they freeze; as a result, cavities develop under individual clasts, and when the soil thaws, the cavities can become partially infilled with sediment. The infilled cavities then prevent these clasts from returning to their original location, resulting in a net upward movement of large clasts. High moisture contents and large clasts favor high rates of upfreezing (Anderson 1988). Thus, upfreezing is optimal in regions with a cool climate and where soils are forming in dominantly silty sediment, with few, but large, clasts.

Within the study area, where thin loess deposits are prevalent and frost can penetrate > 50 cm (Schaetzl and Isard 1996); upfreezing has likely mixed cobbles from the underlying parent material with the overlying silt-rich loess, forming soils that have cobbly silt loam surface textures. Thus, there is an excellent correlation between the NRCS loessal soil surface texture map and the interpolated loess thickness map with the cobbly surface texture modifier, i.e. usually where loess is estimated to be thin and silty (Figures 3.11 and 3.12) the NRCS had mapped a loessal soils with a “cobbly” surface texture modifier (e.g., Champion, Michigamme, Petticoat, and Dishno) (Figure 3.11). In the southern regions of the study area, where loess deposits are generally thicker, loessal soils are dominantly mapped without a “cobbly” surface texture modifier (e.g., Goodman and Wabeno) (Figures 3.11 and 5.16). Here, cryoturbation likely has been less able to mix cobbles from the underlying drift into the loess deposits.

5.3.2.2 Spatial Trends in Sand Contents

For the study area, interpolated maps showing the distribution of sand contents of the loess deposits suggests that in western and northern Marquette County, they have the highest sand contents (Figures 5.21, 5.22, 5.23 and 5.24). For example, Figures 5.21 shows that loess deposits in western Marquette County generally have the highest percentages (~ 22) of sand contents within the 50-75 μm fraction. Moreover, Figure 5.22 shows that these deposits in western Marquette County also have the highest contents within the 75-125 μm fraction. This research indicates that northern and western Marquette County generally has coarser loess than does Iron and Baraga Counties. These data support the decision by NRCS to develop a new soil series for the Marquette County soil survey. In Marquette County, loessal soils dominantly have a cobbly *fine sandy loam* surface texture and are mapped in the Keewaydin series, whereas in Baraga and Iron counties loessal soils dominantly have a *silt loam* or cobbly *silt loam* surface texture and are mapped in the Goodman, Wabeno, Champion, Michigamme, Petticoat, and Dishno series.

A comparison of the NRCS loessal soils surface texture map (Figure 3.11) to the interpolated loess thickness map (Figure 5.16) shows that the Keewaydin series is usually mapped where loess deposits are thin (between ~ 21 and 28 cm). Loess mixing vectors, such as bioturbation and cryoturbation, likely are more efficient in incorporating the coarser underlying sediments into these thin loess deposits, resulting in a coarser loess deposit. However, generally the finer (eolian) fractions of the loess deposits in Marquette County are larger in particle size, i.e., have a larger modal value, than the loess deposits in Baraga and Iron Counties. The relatively coarser loess deposits could have been caused by different source areas, such as more local sources, compared to the loess in Baraga and Iron Counties, which could have had more distant source areas.

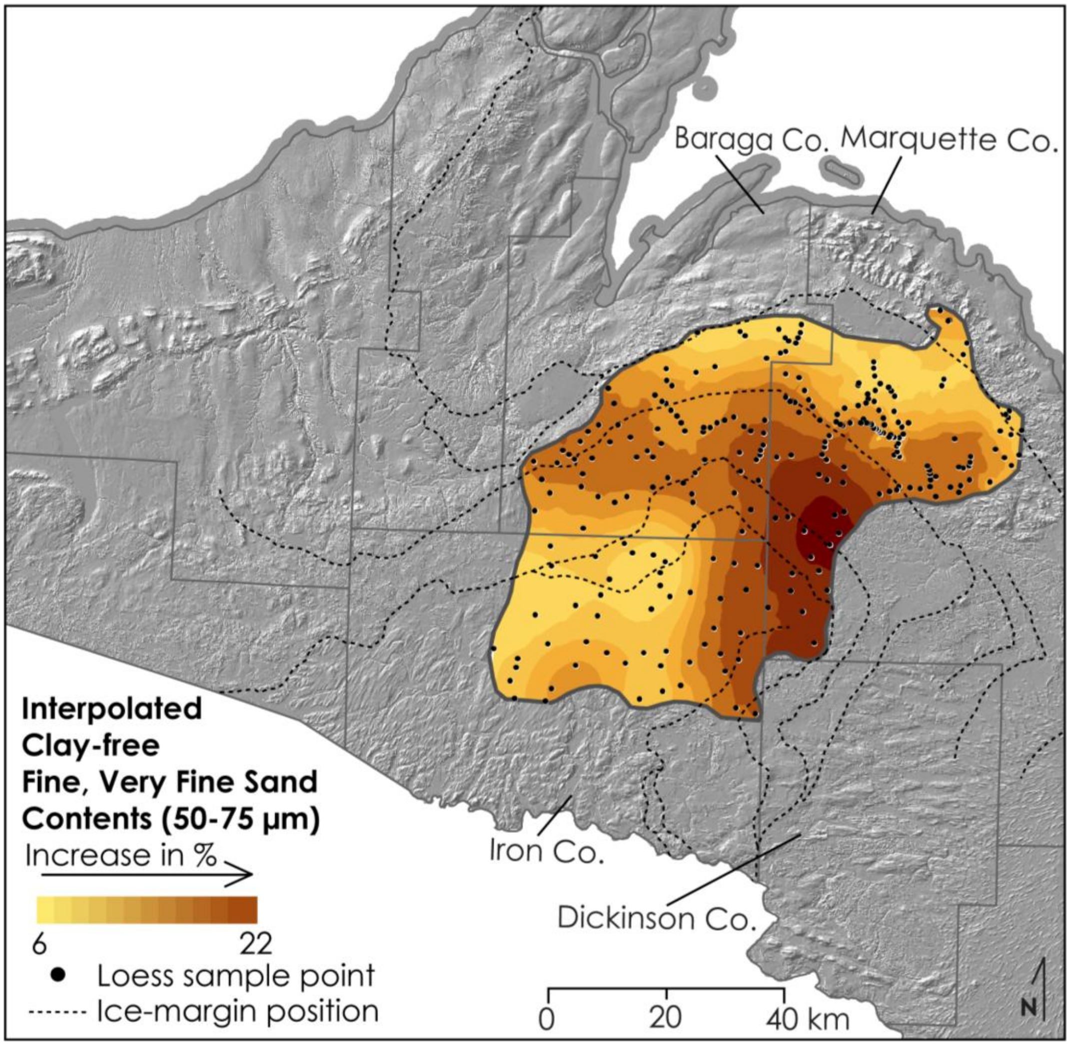


Figure 5.21: Interpolated map showing the distribution of clay-free fine, very fine sand contents.

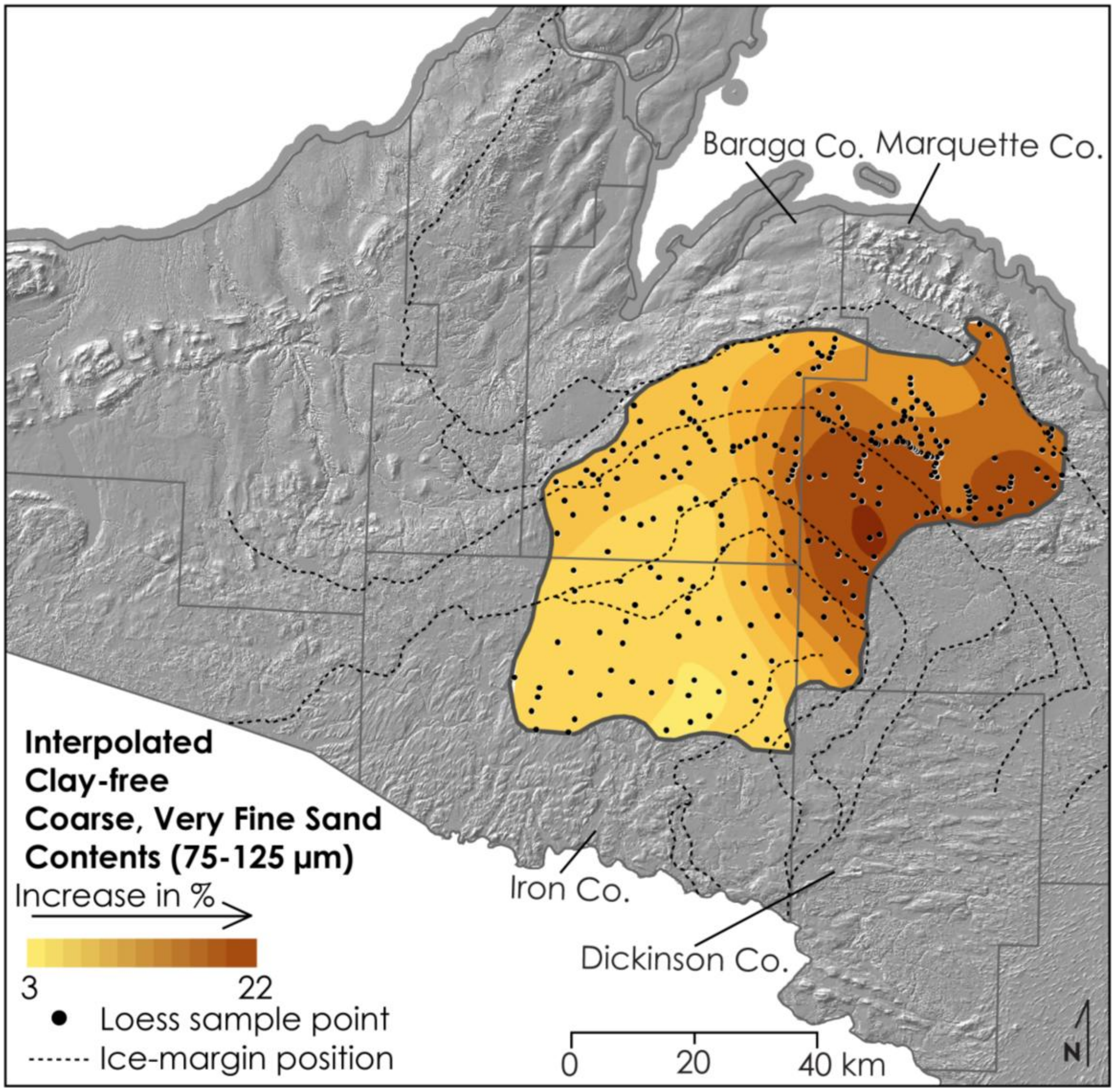


Figure 5.22: Interpolated map showing the distribution of clay-free coarse, very fine sand contents.

Marquette County not only has some of the coarsest loess within the study area (when examining the 50-75 µm fraction only), but loess samples here generally also have the highest percentages of fine, medium, and coarse sand contents. Particles within the 125-1000 µm fraction have probably been mixed via bioturbation and/or cryoturbation into the loess column from the underlying sandy drift material. Interpolated maps show that northwestern Marquette County loess deposits generally have the highest percentages of contents within the 125-175 µm, 175-250 µm, and 250-500 µm fractions (Figures 5.23, 5.24 and 5.25). Loess deposits in northwestern Marquette County are estimated to have ~ 12 percent fine, fine sand (125-175 µm fraction), ~ 13 percent coarse, fine sand (175-250 µm fraction), and ~ 31 percent medium sand (250-500 µm fraction) (Figures 5.23, 5.24 and 5.25). Conversely, the loess samples in Baraga and Iron Counties generally have less than 5 percent of their loess contents within these size fractions. Loess deposits in the northern regions of the study area are generally thinner (Figure 5.16), facilitating the likelihood that the loess has been mixed with the underlying parent material. Moreover, the spatial pattern of samples with high sand contents matches well with the distribution of ETC types. Loess deposits in northwestern Marquette County usually have a textural curve that is bimodal with one mode in the 250-1000 µm fraction or they are unimodal with a mode in the 250-1000 µm fraction (i.e., ETC types 3 and 5) (Figures 5.14 and 5.15). The interpolated maps (Figures 5.21, 5.22, 5.24 and 5.25) show a distribution of sand contents within the loess area that agrees with the NRCS loessal soil series maps. Loessal soils in northwestern Marquette County are generally mapped as Keewaydin, which is described as having a cobbly, fine sandy loam surface texture. Goodman, Wabeno, Champion, Michigamme, Petticoat, and Dishno soils are mainly mapped in Baraga and Iron Counties; they are loessal soils with silt loam or cobbly silt loam surface textures (Figures 3.11, 5.16, 5.23, 5.24 and 5.25). In sum, both the interpolated sand contents maps and the NRCS loessal soil series maps show that loess deposits in the northern regions of the study area are generally thinner and texturally coarser than the deposits in the western and southern regions of the study area.

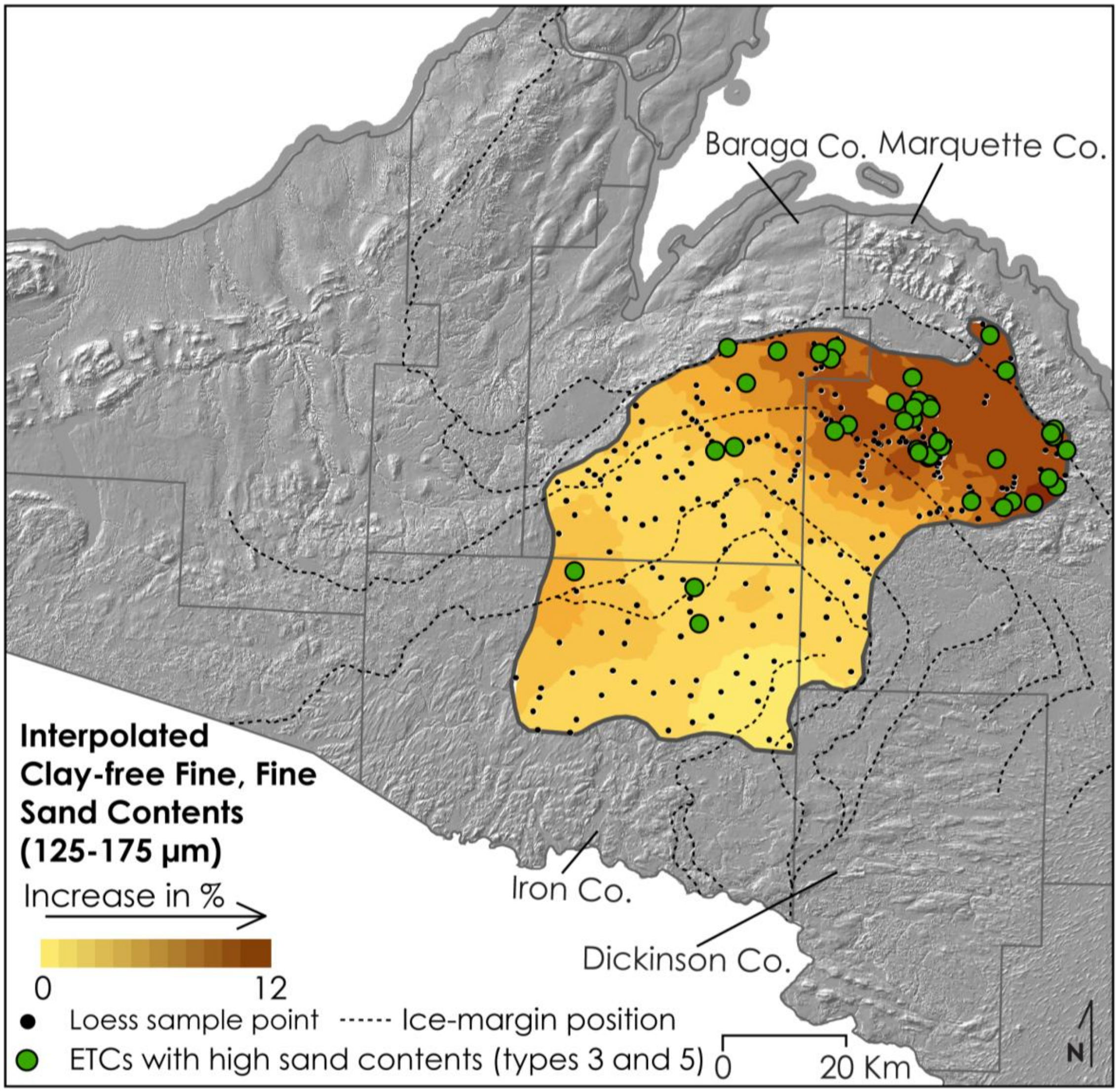


Figure 5.23: Interpolated map showing the distribution of clay-free fine, fine sand contents.

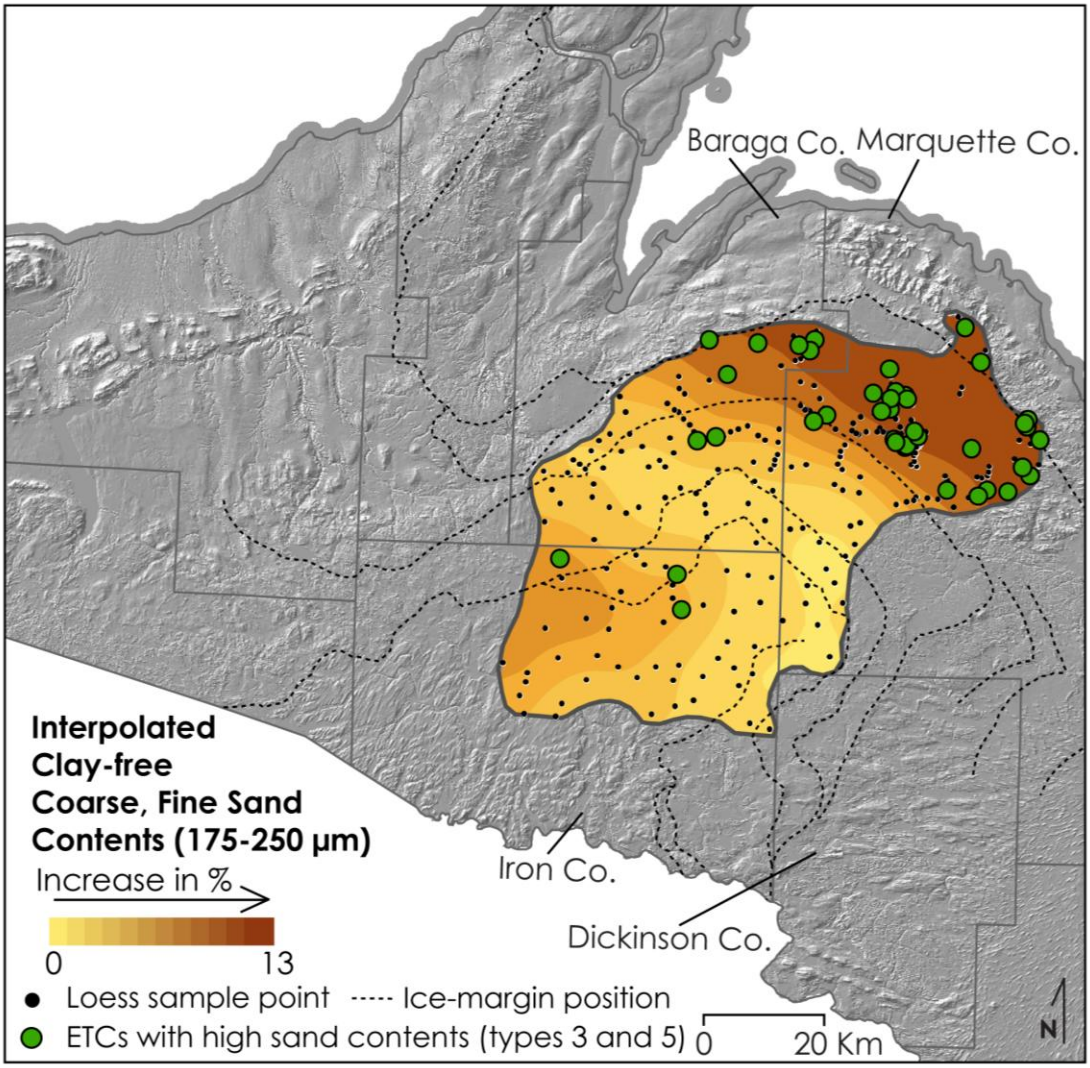


Figure 5.24: Interpolated map showing the distribution of clay-free coarse, fine sand contents.

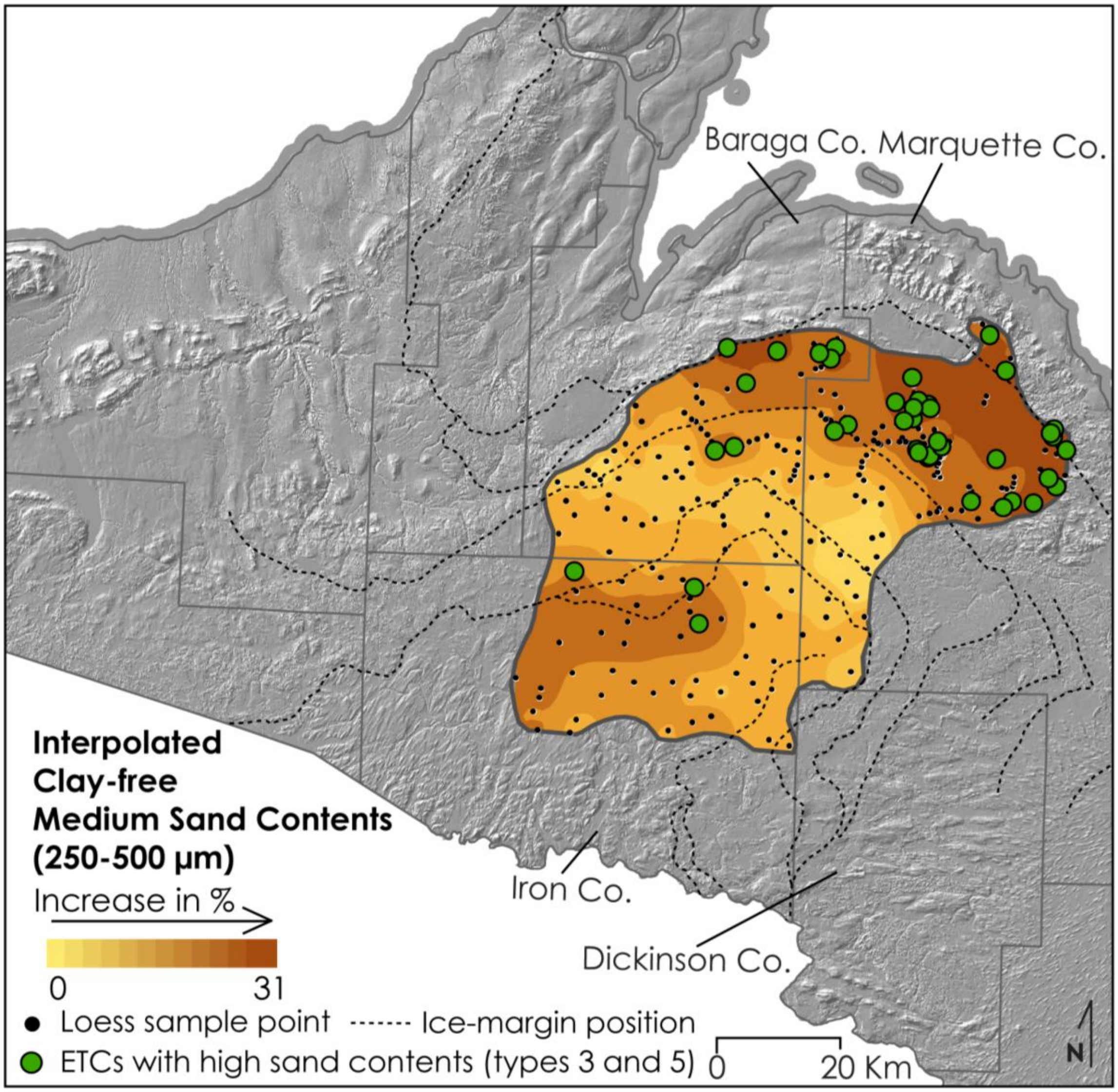


Figure 5.25: Interpolated map showing the distribution of clay-free medium sand contents.

5.3.2.3 Spatial Trends in Modal Particle Size

As a whole, the study area has thin (mean thickness of ~ 37 cm) loess deposits (Figure 5.16). Generally, the loess deposits have bimodal continuous textural curves, with particle size peaks in both within the 25-75 µm fraction and in the 250-500 µm fractions (Figures 5.4, 5.6, 5.7, 5.8 and 5.10). The textural bimodality of these loess deposits, particularly the wide disparity in sizes between the two modes, suggests that the sediments making up the loess deposits are polygenetic. I am suggesting that the silt size particles likely originated as loess, while the coarser sandy particles originated as glacial outwash or till; after loess deposition, the coarser underlying sediments have been mixed with and into the overlying loess. The modal particle size within each particle size fraction (e.g., silt and sand) is one of the most important characteristics of these loess deposits, and thus, should be analyzed/mapped separately in order to identify potential source areas. Therefore, two maps were compiled in order to further support the hypothesis that the silt or fine, very fine sand contents of the soil samples originated as loess, and the coarser contents are of a different origin.

Within the study area, ~ 95 percent of the samples have a modal particle size within the 26-99 µm fraction. Additionally, ~ 60 percent of the samples have a bimodal continuous texture curve, with one peak in the 26-99 µm fraction and another peak in the 200-780 µm fraction. If the contents within 26-99 µm fraction originated via eolian processes, as would seem logical, then this size fraction should display a clear and explainable spatial trend in particle size, from a potential source area. Conversely, lack of a spatial trend should be evident when interpolating particle size distributions within the 200-780 µm fraction, because these particles most likely did not originate via eolian processes, but instead by direct glacial processes.

The map of "silt modes" was compiled by assigning each sample its modal value within the 26-99 µm fraction, as reported by the Malvern Mastersizer 2000. This mode was then added to the GIS shapefile (e.g., Figure 5.26). The "sand mode" map was produced in similar fashion, using the data from the 200-780 μm fraction (e.g., Figure 5.27). However, not all samples were used for each modal map, because some samples have a shoulder curve, and thus, only one "true" mode. Nonetheless, each sample has at least one mode, and therefore each sample point was assigned to at least one mode in the data set. Sample types 1-4 were used to generate the silt mode map (Figure 5.28), and sample types 2, 3 and 5 were used to generate the sand mode map (Figure 5.29).

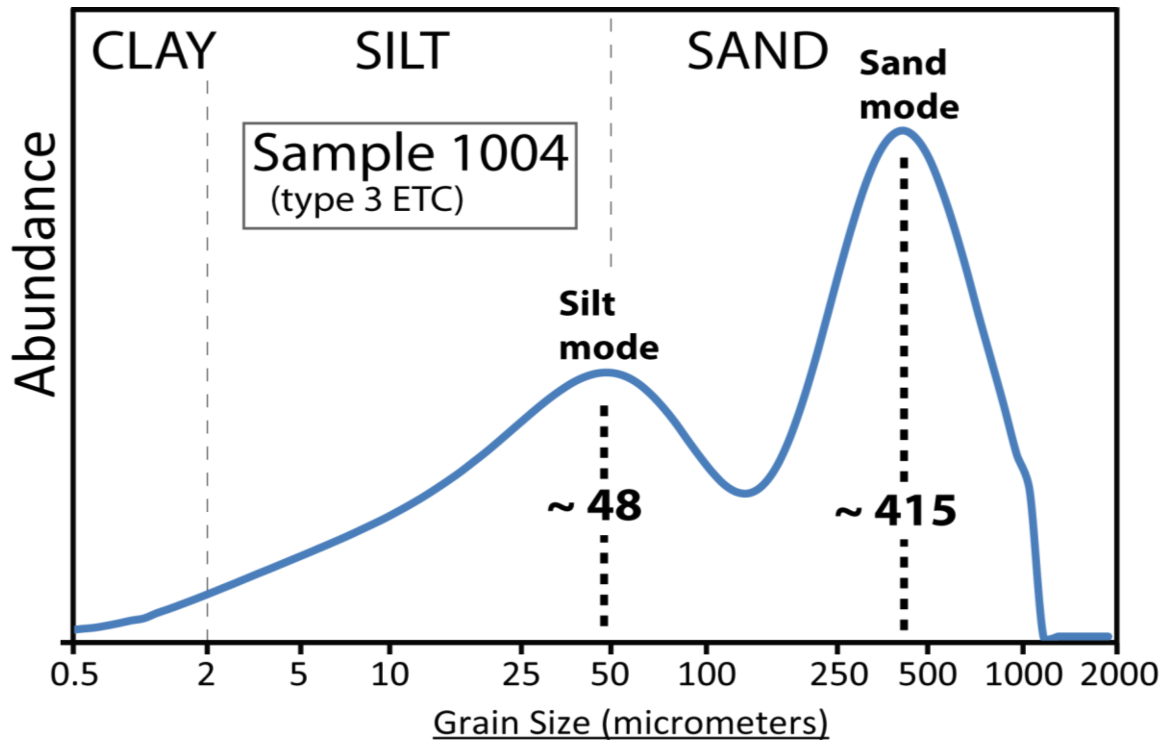


Figure 5.26: As an example, this type 3 sample taken from the study area was assigned a 48 μm silt mode and a 415 μm sand mode, for the two modal maps.

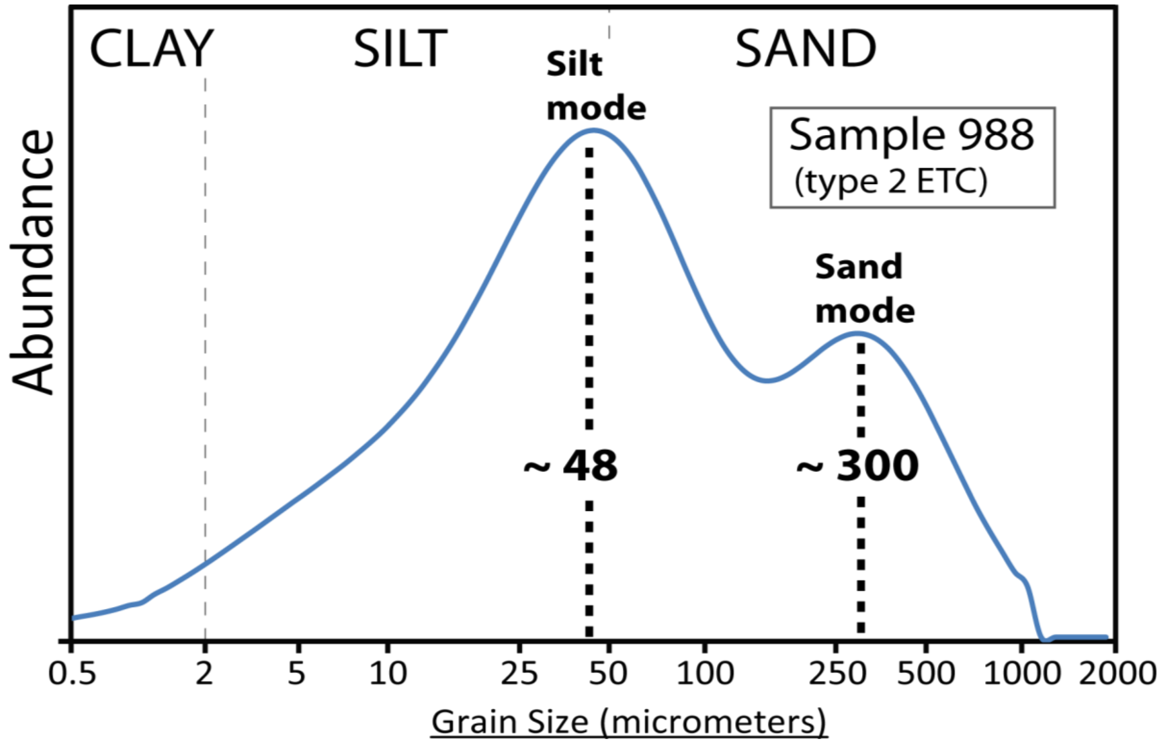


Figure 5.27: As an example, this type 2 sample taken from the study area was assigned a 48 µm silt mode and a 300 µm sand mode, for the two modal maps.

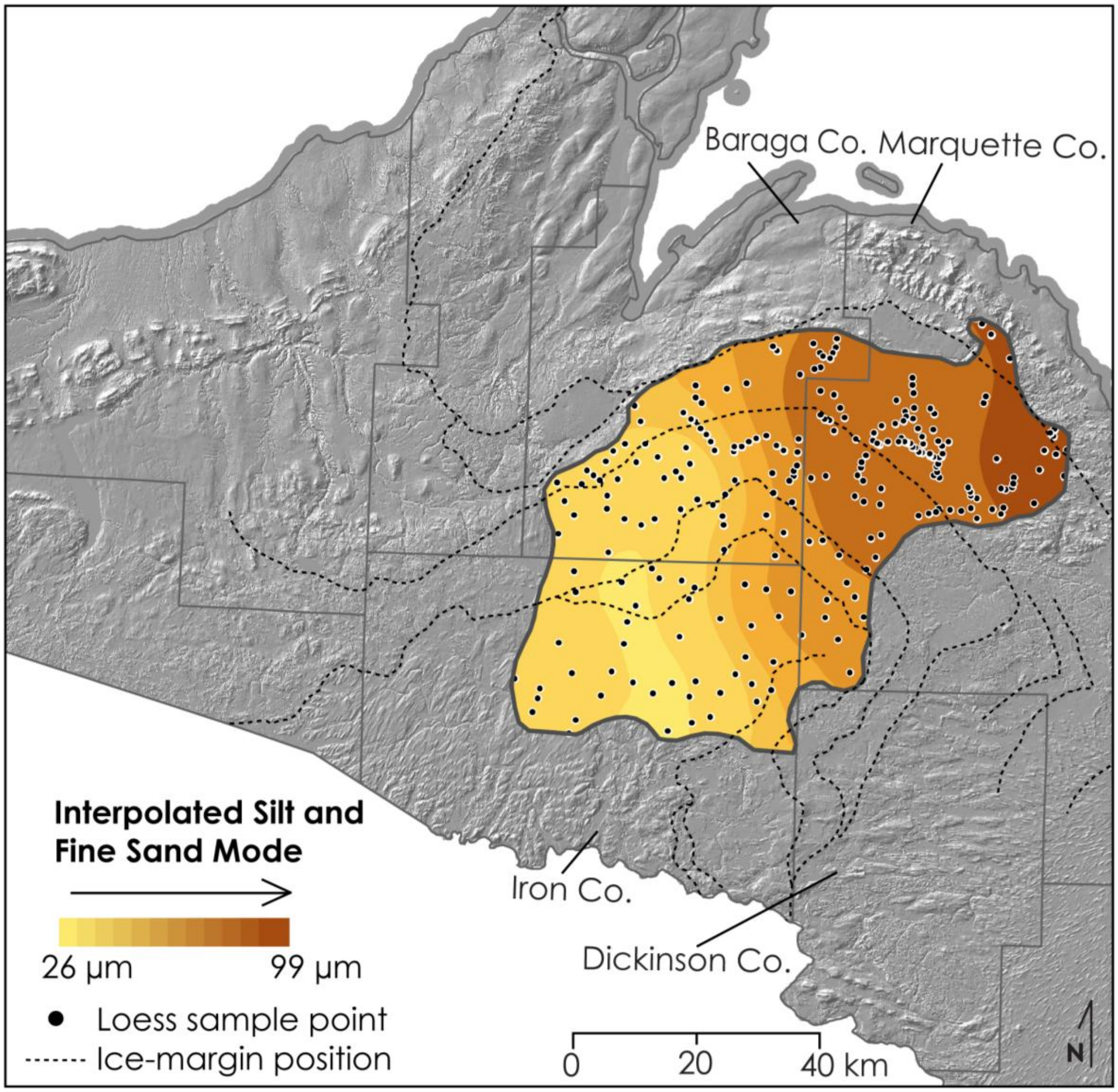


Figure 5.28: A map illustrating modal particle size of eolian sediment in the study area, using sample modes within the 26-99 µm fraction. Samples without a "true" mode within the 26-99 µm fraction, such as type 5 ETCs, were not used in this kriging exercise.

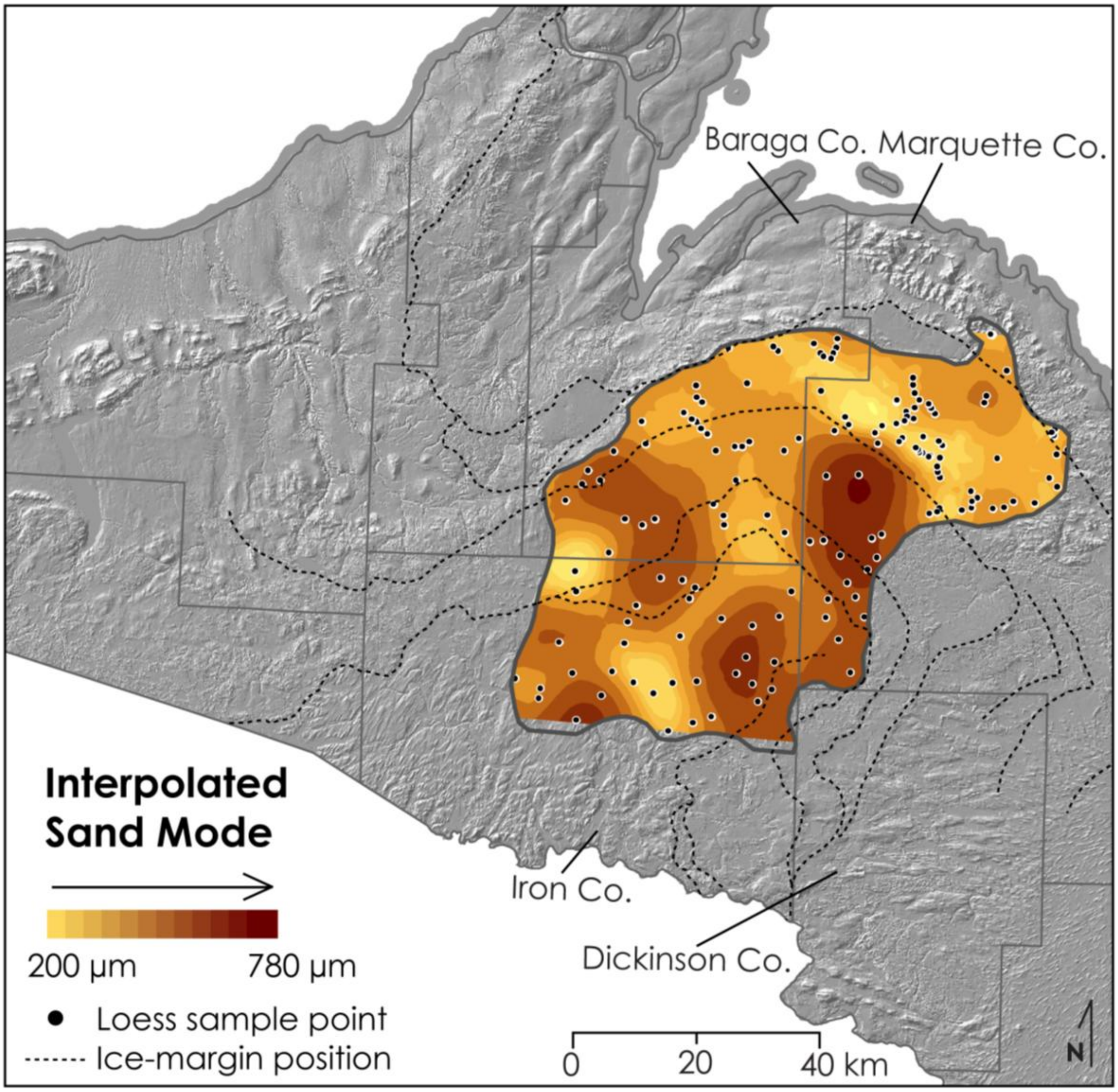


Figure 5.29: A map illustrating modal particle size of coarser sediment in loess samples, within the study area. Samples without a "true" mode in the 200-780 fraction, such as types 1 and 4 ETCs, were not used in this kriging exercise.

The silt mode map (Figure 5.28) illustrates a prominent southwest to northeast spatial trend, with the southern regions of the study area having samples with the finest modal particle size (~ 26 µm), and the northeastern region having samples with a coarser mode (~ 99 µm). Loess deposits generally become progressively finer in texture away from the source area(s), thus, the silt mode map points to a predominantly northeastern source area for the Peshekee Loess.

The sand mode map (Figure 5.29) depicts no clear spatial trend, and instead shows several regions with coarser sand modes (~ 780 µm). The sand mode map provides evidence that the coarser contents within the loess samples were not transported via eolian processes. Many of the regions with large sand modes are located in the southern portion of the study area, where loess samples are also known to have the finest silt modes. Within the study area, it is possible to have areas where there is a high percentage of silt or fine, very fine sand contents in addition to medium and coarse sand contents because loess deposits in this area often have a bimodal textural curve (e.g., type 2 ETCs). The modal maps provide additional evidence that the underlying, coarser sediments, likely originated before the loess, and have since been mixed into the loess.

Loess deposits are generally thicker and coarser near their source and become thinner and finer-textured downwind (Smith 1942; Frazee et al. 1970; Olson and Ruhe 1979; Muhs and Bettis 2000). The silt modal particle size map suggests a dominantly northern source area, which stands in opposition to the interpolated loess thickness map, that suggests a southern source area(s). In this section, I will attempt to explain this apparent disparity.

Loess deposits are usually thickest in the southern regions of the study area and progressively thin towards the north, whereas modal particle size is coarsest in the north and becomes progressively finer towards the south (Figures 5.16 and 5.28). If the dominant source area(s) is (are) in the southern parts of the study area, or even areas beyond it to the south, as the loess thickness map suggests, then silt modal particle size should progressively become finer towards the north. However, the silt mode map shows that the particle size mode of loess samples within the study area gradually gets coarser towards the north. These seemingly contradictory spatial trends could be a result of multiple and heterogeneous source areas within the study area, i.e., there are actually multiple loess sections within the study area. I believe that, despite the apparent conflict between the loess thickness and modal particle size trend maps, the loess deposits in the southern regions of the study area were likely sourced from landscapes outside (and south) of the study area. The loess deposits here, particularly those in Iron County, probably originated from more distant sources. Evidence for this is the dominantly smaller particle size fraction (~ 26 µm) (Bigsby 2010). I also suggest that sandy, but thin, loess deposits in the northern regions were sourced from more localized landscapes, which would explain the dominantly coarser particles (~99 µm). This topic is discussed in more detail below.

5.4 Peshekee Loess Individual Sections and Potential Source Areas

Spatial characteristics of loess deposits not only aid in the identification of a sediment as eolian, but can also point to provenance (Schaetzl and Hook 2008). At a large scale, the study area shows several spatial trends in loess thickness, silt and sand contents, and modal particle size, even though some of these trends appear to be contradictory across the larger region (Figures 5.16, 5.17, 5.21 and 5.28). One way to alleviate this potential problem is to examine the loess characteristics at a larger scale and determine whether or not the textural character and thickness of individual loess deposits varies between these smaller regions within the larger loess region. Here, within the study area, this approach may be advantageous, because the loess is highly variable spatially, and loess is absent at many sites. Analyzing the Peshekee Loess at a larger scale could potentially tease out the conflict between modal particle-size and loess thickness, and point to more than one source area for the loess.

In this thesis, each smaller loess region, within the larger study area, is referred to as a "section." The study area was divided into four sections, in order to better differentiate the types of loess deposits within it, and to suggest possible, unique source areas for each section. The four sections were named for their unique loess character and for a physical or cultural feature of prominence that is within that section. From south to north, the four sections are Amasa, Covington, Republic, and Champion (Figures 5.30 and 5.31). The delineation of these sections was largely driven by spatial patterns of loess thickness, modal particle-size, percentage of contents within the 25-75 µm fraction (i.e., the loess), and the percentage of contents within the 125-500 µm fraction (i.e., the in-mixed sand) (Table 5.7; Figures 5.16, 5.17, 5.21 and 5.28). Below is a discussion of the specific criteria and logic that were used to define the section boundaries.

The boundary between the Amasa and Covington sections follows the isoline that represents 63 percent clay-free silt content (2-50 µm fraction). This boundary was used because the loess samples within these two sections generally have a high percentage of clay-free silt, in comparison to the Champion and Republic sections, which have less. The Champion section boundary, where it abuts the Covington and Republic sections, follows the isoline that represents 39 percent clay-frees silt content (Figure 5.30). The Republic section boundary, where it is adjacent to the Amasa and Champion sections, is marked by the isoline that represents 16 percent clay-free fine, very fine sand content (Figure 5.31).

Not all areas within the study area fall within a section boundary, proper, using the above boundary definition criteria. Because it was deemed necessary for all areas within the study area to be classified within a section, some of the section boundaries were therefore slightly adjusted. For areas where there exists a gap between two section boundaries, the gap was divided into two roughly equal parts; half of that area was given over to each of the two bounding sections. This "cut" operation was done in a GIS, by visual inspection. Moreover, for discussion purposes, only the samples that are representative of the loess in that section (i.e., those labeled with a white point) are illustrated in Figures 5.30, 5.31, 5.32, 5.36, 5.40, and 5.41. Most of these samples occur within the "original" section boundaries. The remaining segments of this chapter will focus on these four sections. I will illustrate and discuss the characteristics of the loess deposits within the four sections, and suggest possible source area(s) for them.

Table 5.7: Characteristics of the four major loess sections within the study area.

	Amasa Section (n=37)	**Covington Section (n=77)**	**Republic Section (n=19)**	**Champion Section (n=126)**
Most common ETCs	Type 2 (89.2%) and type 1 (5.4%)	Type 2 (42.9%) and type 4 (35.1%)	Type 2 (52.6%) and type 1 (36.8%)	Type 2 (36.5%) and type 4 (29.4%)
Mean Loess thickness	52.4 ± 13.1 cm	36.9 ± 13.9 cm	42.5 ± 11.8 cm	32.9 ± 10.3 cm
Mean modal particle-size within the 26-99 µm fraction	38.6 µm	40.2 µm	49.8 µm	52.9 µm
Mean % contents within the 25-75 µm fraction	38.5%	39.6%	47.2%	33.0%
Mean % contents within the 250-500 µm fraction	9.9%	8.2%	5.5%	13.4%

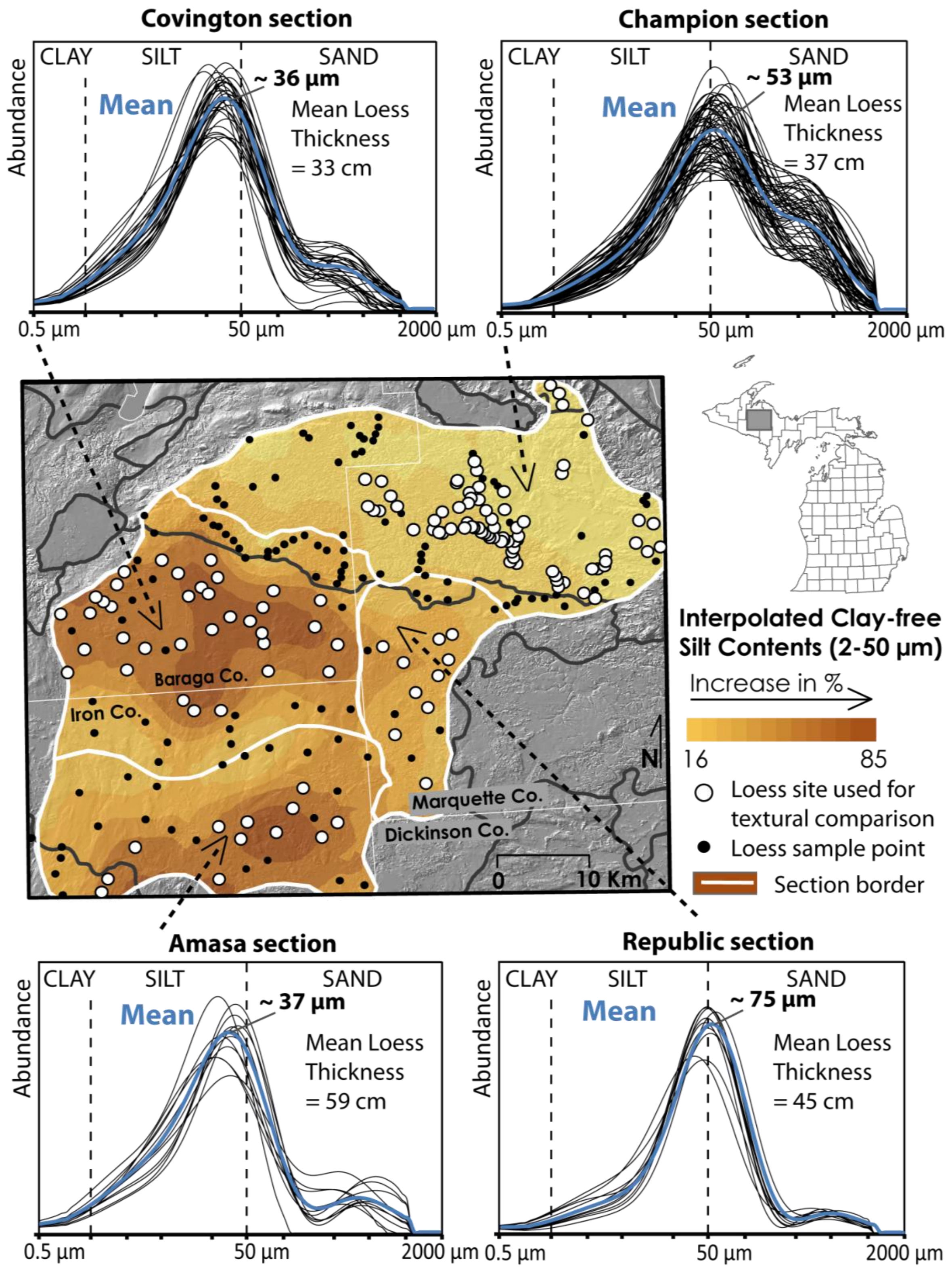


Figure 5.30: Map of interpolated clay-free silt contents and a comparison of loess samples' textural curves within four loess sections, in the study area.

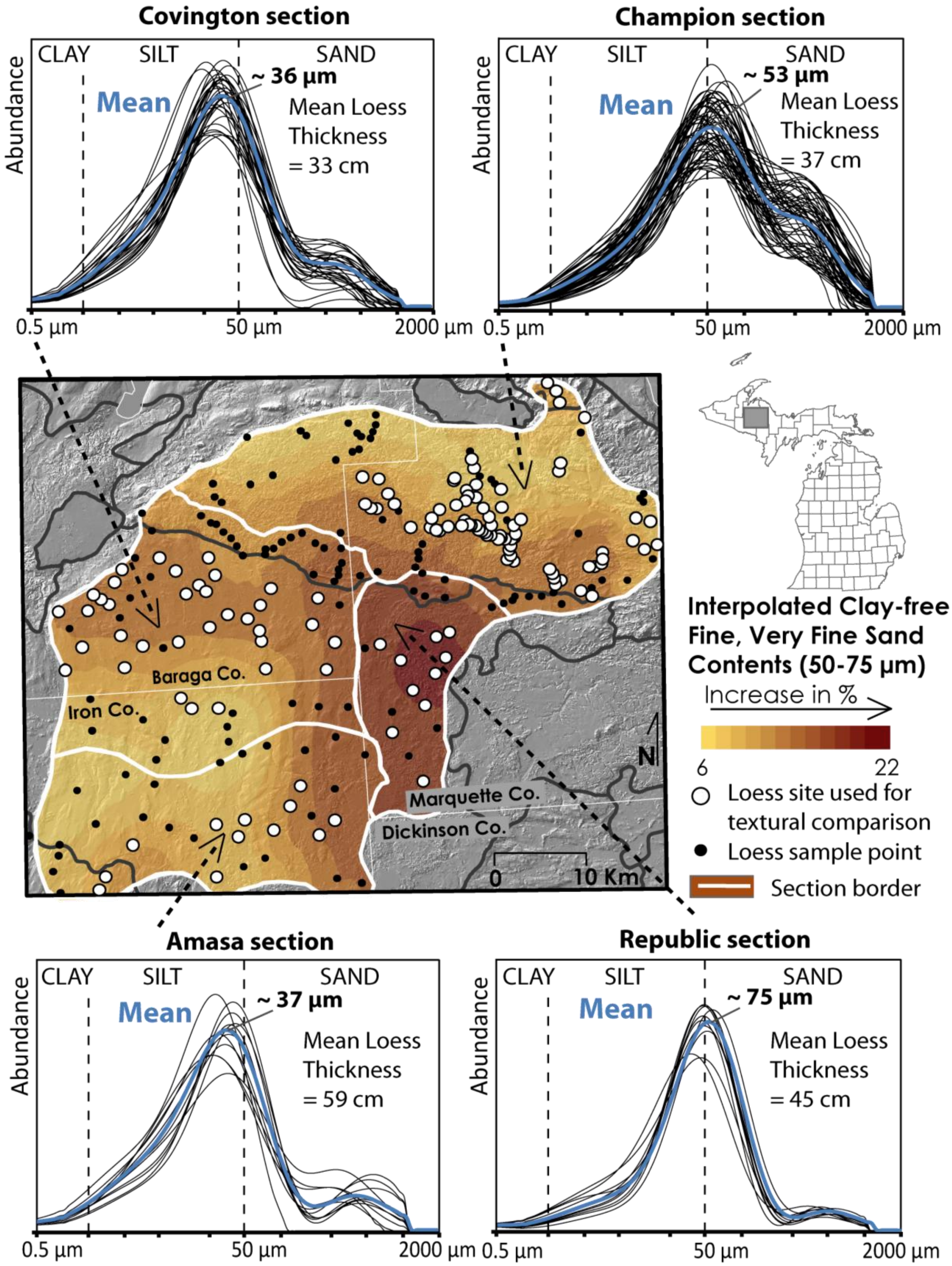


Figure 5.31: Map of interpolated clay-free fine, very fine sand (50-75 um) contents and a comparison of loess samples' textural curves within four loess sections, in the study area.

5.4.1 Amasa Section

The loess deposits near the southern margins of the study area are some of the thickest and siltiest deposits within the study area (Tables 5.7 and 5.8). I have named these loess deposits, in Iron County, the Amasa section. The most common eolian textural curve in this section is the type 2; ~ 89 percent (n= 37) of the samples recovered within this section exhibited a type 2 ETC (Table 5.7). The most common eolian textural curve for the remaining sections was also a type 2, however their percentage of samples with this type curve are all lower and range between ~ 53 and 37 percent. Moreover, the Amasa section has the greatest loess thicknesses, with a mean thickness of 52.4 ± 13.1 cm, whereas to the remaining three sections have mean loess thicknesses that range between ~ 33 and 43 cm (Tables 5.7 and 5.8; Figure 5.16). Several continuous textural curves selected from the Amasa section show that loess deposits here usually have a modal particle-size within the 25-50 µm fraction, and small peak in the 250-500 µm fraction (Figure 5.32). The mean modal particle-size (within the 26-99 µm fraction) in the Amasa section is 38.6 µm, which is a much finer mean modal particle-size, as compared to the Covington, Republic and Champion sections, with a mean ranging between 40.2 and 52.9 µm (Tables 5.7 and 5.8).

Table 5.8: A table ranking the four loess sections, within the study area, by calculating each of the sections mean loess thickness and the mean of several particle-size fractions.

Loess characteristic	**Amasa Section (n=37)**	**Covington Section (n=77)**	**Republic Section (n=19)**	**Champion Section (n=126)**
Mean:	***Rank (Red being the highest and pink being the lowest)***			
Loess thickness	52.4%	36.2%	42.5%	32.9%
Medium silt (25-35 µm)	12.3%	12.4%	12.6%	9.1%
Coarse silt (35-50 µm)	13.4%	13.7%	16.3%	11.1%
Total silt (2-50 µm)	52.2%	52.6%	49.6%	38.6%
Fine, very fine sand (50-75 µm)	12.8%	13.5%	18.2%	12.8%
Medium sand (250-500 µm)	9.9%	8.2%	5.5%	13.4%
Coarse sand (500-1000 µm)	5.8%	4.1%	3.1%	6.2%

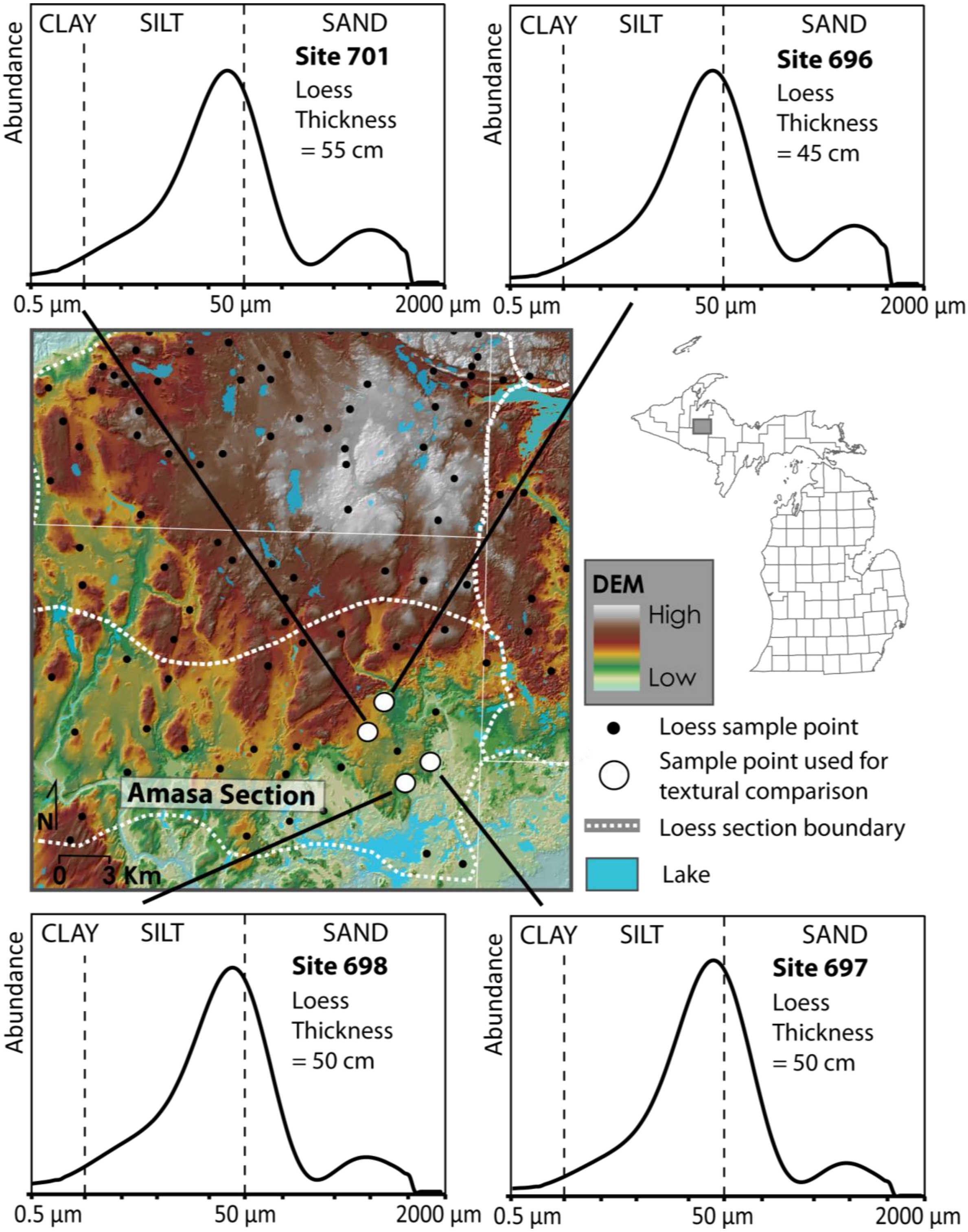


Figure 5.32: An example of four continuous textural curves from the Amasa section. Note that the textural curves are very similar and all have a mode within the coarse silt fraction (35-50 um).

Greater loess thicknesses in the Amasa section, coupled with finer textures, suggest that the loess deposits here are a distal part of the thicker, Iron County Loess. The Iron County Loess is located primarily in Iron County, Michigan, and extends a few kilometers into Baraga, Gogebic, and Marquette Counties, and into bordering counties in Wisconsin. Bigsby (2010) and Scull and Schaetzl (2011) showed that the loess deposits in Iron County are thickest in southern and central Iron County (between ~ 50 and 85 cm thick). Early evidence from Bigsby (2010) suggested that the Iron County Loess was receiving eolian sediment from multiple source areas; each source area was likely contributing different sizes of eolian sediment. The loess deposits are presumably thickest in southern and central Iron County because the landscape was a glacial re-entrant (Bigsby 2010). Here, the landscape is bordered by several ice-marginal positions formed by four separate glacial lobes (Attig et al. 1985; Peterson 1985, 1986).

The uplands in southern and central Iron County would have likely been ice-free and stable earlier than the surrounding areas, in addition to being at higher elevations, allowing more time for loess to accumulate there. Although Bigsby's (2010) work is on-going, the Vilas County Outwash Plains, and the morainic features bordering Iron County, are thought to have been sources for the ICLS. The Vilas County Outwash Plains are the southern-most (and largest) source area identified by Bigsby (2010) for the Iron County Loess. Strong, chaotic winds likely deflated the fine-grained sediments from these outwash plains and deposited them on stable uplands, e.g., drumlins in Iron County. Once the Green Bay, Michigamme, Keweenaw, and Ontonagon lobes retreated north from the Sagola, Republic, and Watersmeet ice-marginal positions, these morainic landscapes could have contributed additional fine-grained sediments to the Iron County Loess (Figures 5.33 and 5.34). Because southern and central Iron County likely became subaerial first, loess deposits are generally thicker here. Figures 5.34 and 5.35 illustrate the loess thickness trend and spatial distribution of silt contents within the Amasa section, in relation to the entire Peshekee Loess, the Vilas County Outwash Plains, and the ice-marginal positions; these maps are overlain onto the NRCS soil surface texture map.

My research provides additional data and supports the prior work of Bigsby (2010) on the Iron County Loess. My work has joined the Peshekee Loess and the Iron County Loess, in the Amasa section, which is likely the distal end of the thicker, and more extensive, Iron County Loess. This research suggests that the loess in the Amasa section came from a distant source because of its fine modal particle-size. The Vilas Outwash Plains were likely a major source area for the Amasa section because (1) the outwash sediments were exposed earlier, as compared to the surrounding areas, (2) the finer modal particle-size of the Amasa loess suggests a distant source, and (3) the interpolated loess thickness. Bisgby (2010) as well as and Scull and Schaetzl (2011) showed that loess progressively thickens towards southern Iron County (Figures 5.34 and 5.35).

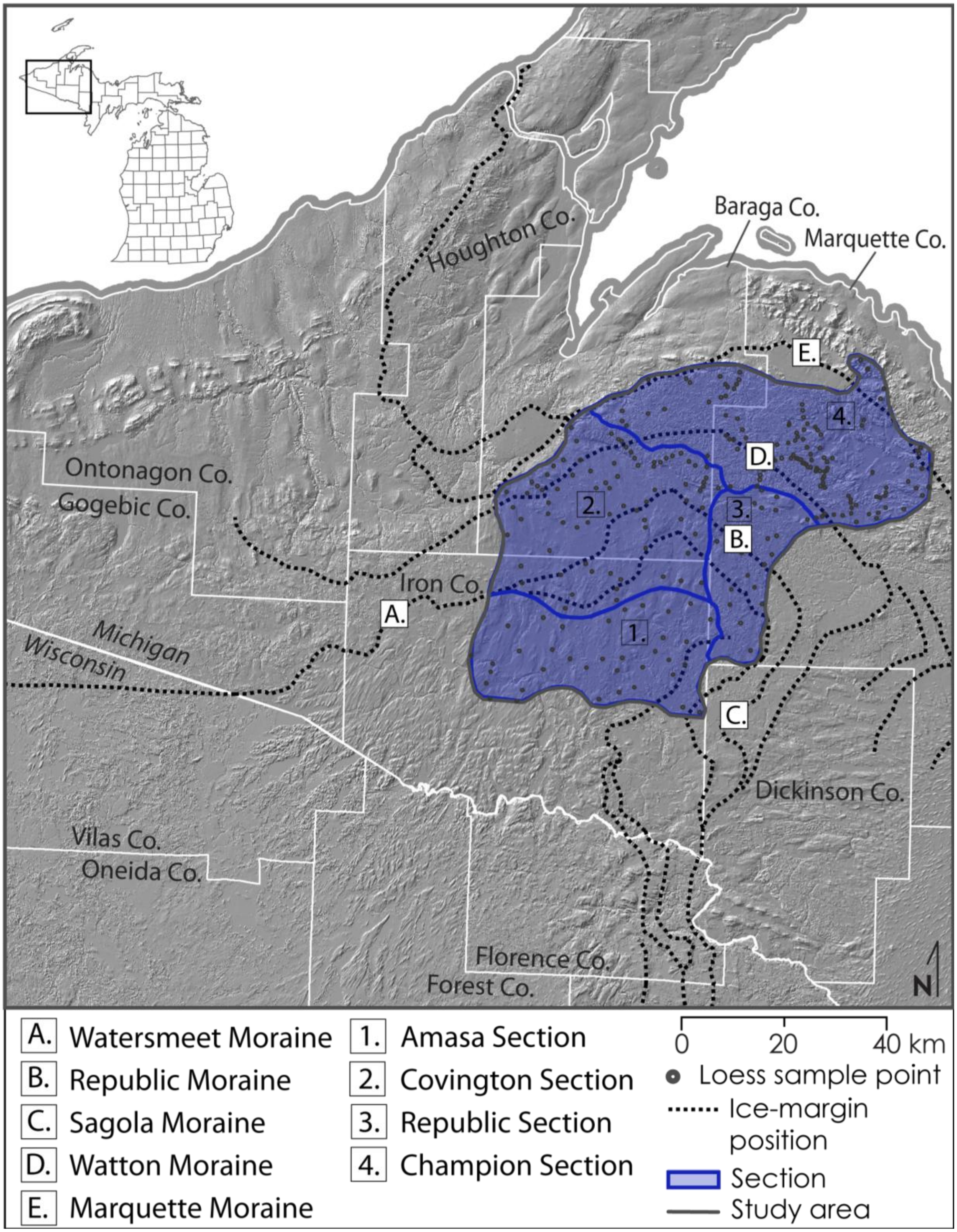


Figure 5.33: Ice-margin positions in the western Upper Peninsula of Michigan and loess sections within the study area. The ice-margins were determined using the work of Attig et al. (1985), Peterson (1985, 1986) and various NRCS county-level soil surveys.

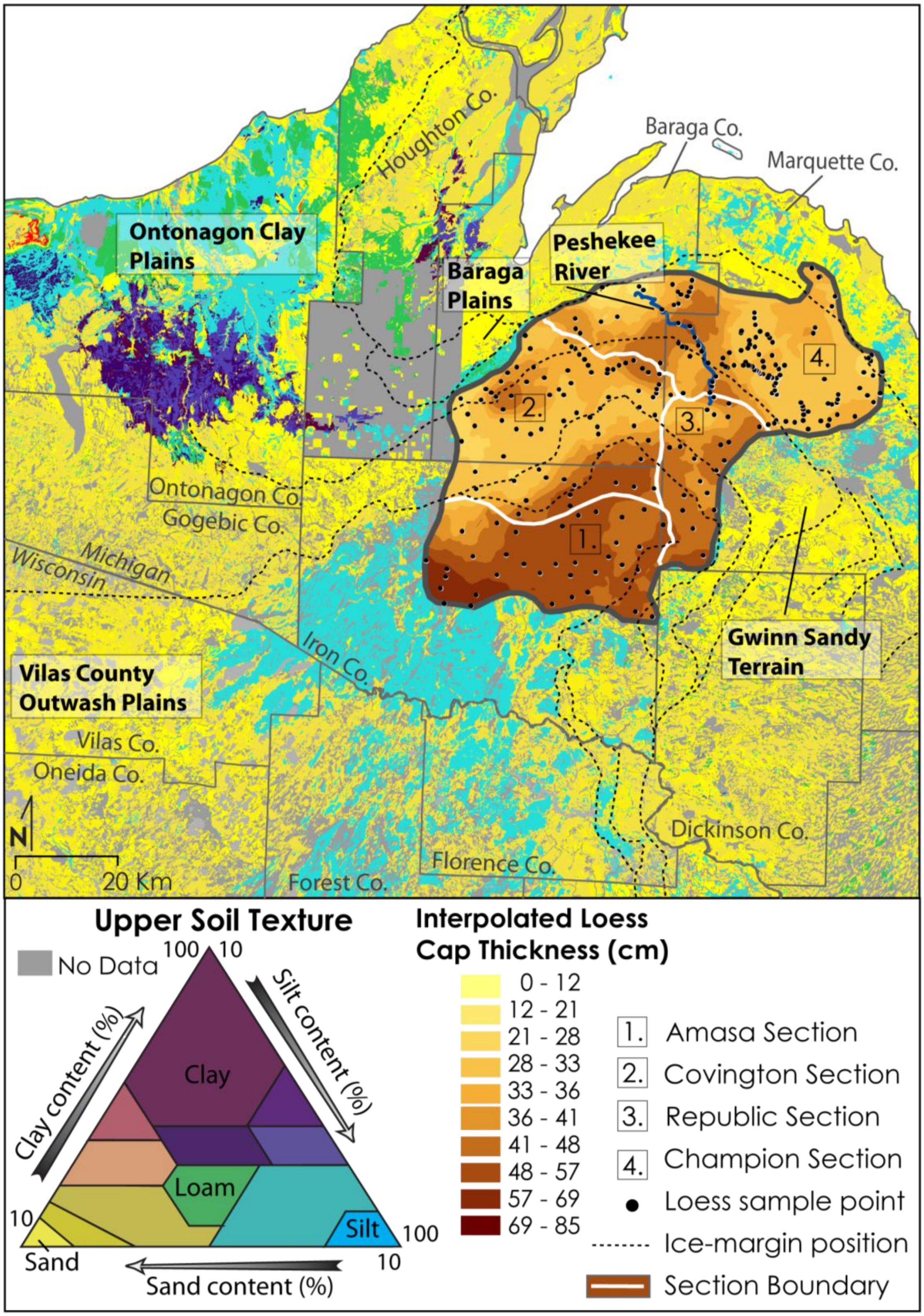


Figure 5.34: Map of interpolated loess thickness, overlain on the NRCS soil surface texture map. The four smaller loess sections are shown in relation to the potential source

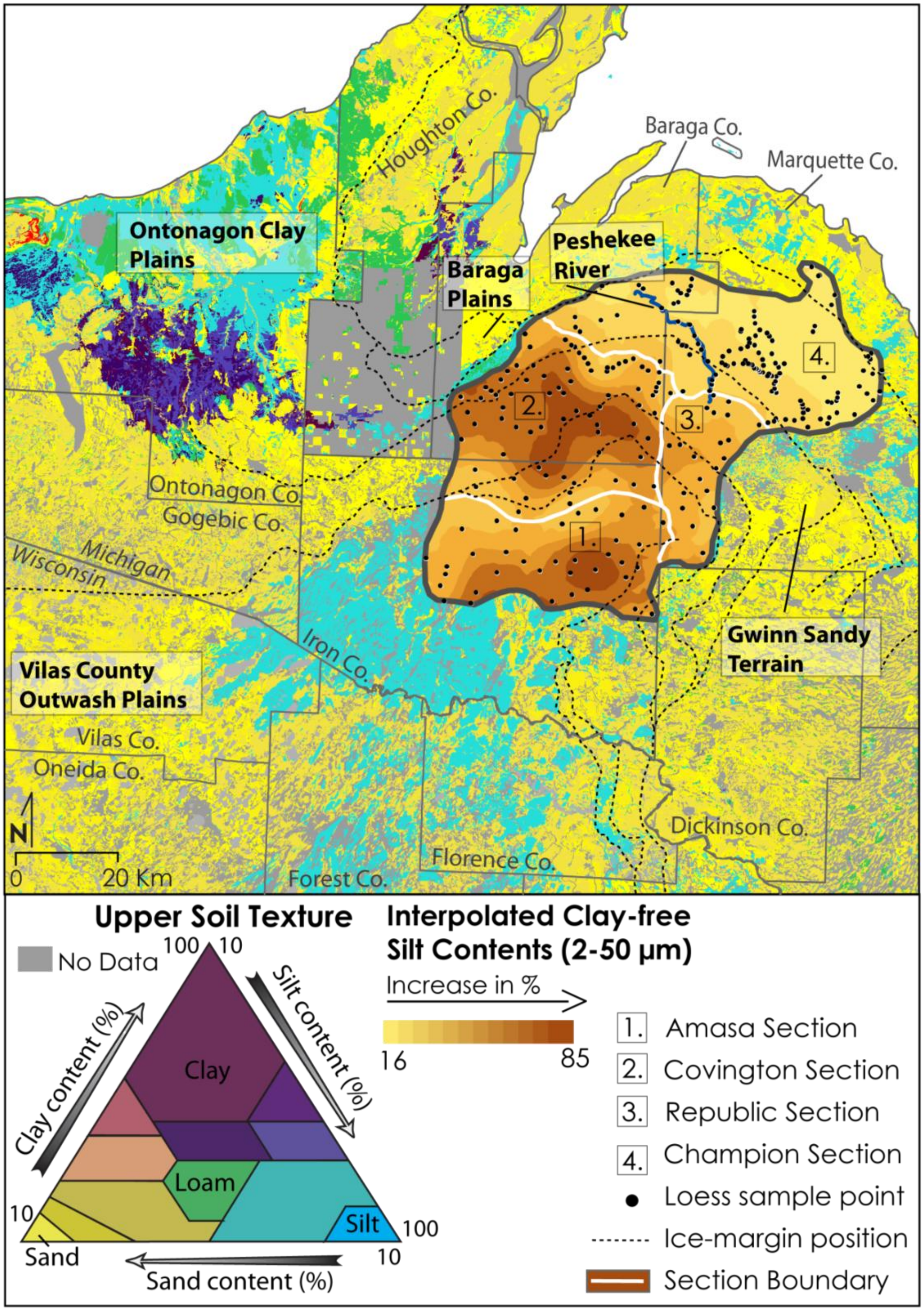


Figure 5.35: Map of interpolated distribution of clay-free silt contents, overlain onto the NRCS soil surface texture map. The four smaller loess sections are shown in relation to the potential source areas.

5.4.2 Covington Section

North of the Amasa section is the Covington section, located mainly in southern and eastern Baraga County. Loess deposits in the Covington section generally are silty, similar to those in the Amasa section (Tables 5.7 and 5.8). However, loess in the Covington section is generally thinner than in the Amasa section (Table 5.7). The mean loess thickness for the Covington section is 36.9 ± 13.9 cm and the mean total content within the 25-75 µm fraction is 39.6 percent; in contrast, the Amasa section has a mean loess thickness of 52.4 ± 13.1 cm and a mean total content within the 25-75 µm fraction of 38.5 percent (Table 5.7). Texturally, the Covington loess deposits usually have a bimodal textural curve or a shoulder curve, with a modal particle-size within the 35-50 µm fraction and a small, secondary peak in the 250-500 µm fraction (Figure 5.36). The first and second most common ETCs within the Covington section are type 2 and type 4; ~ 43 percent of the samples within this section have a type 2 ETC and ~ 35 percent of the samples exhibit a type 1 ETC (Table 5.7). The mean modal particle-size within the 26-99 µm fraction for the Covington section is 40.2 µm, which is similar to the Amasa section where the mean modal particle-size within the 26-99 µm fraction is 38.6 µm (Table 5.7). Conversely, the Republic and Champion sections have a mean modal particle-size within the 26-99 µm fraction of ~ 50 µm and 53 µm, respectively, which is much coarser than loess in the Covington and Amasa sections (Table 5.7).

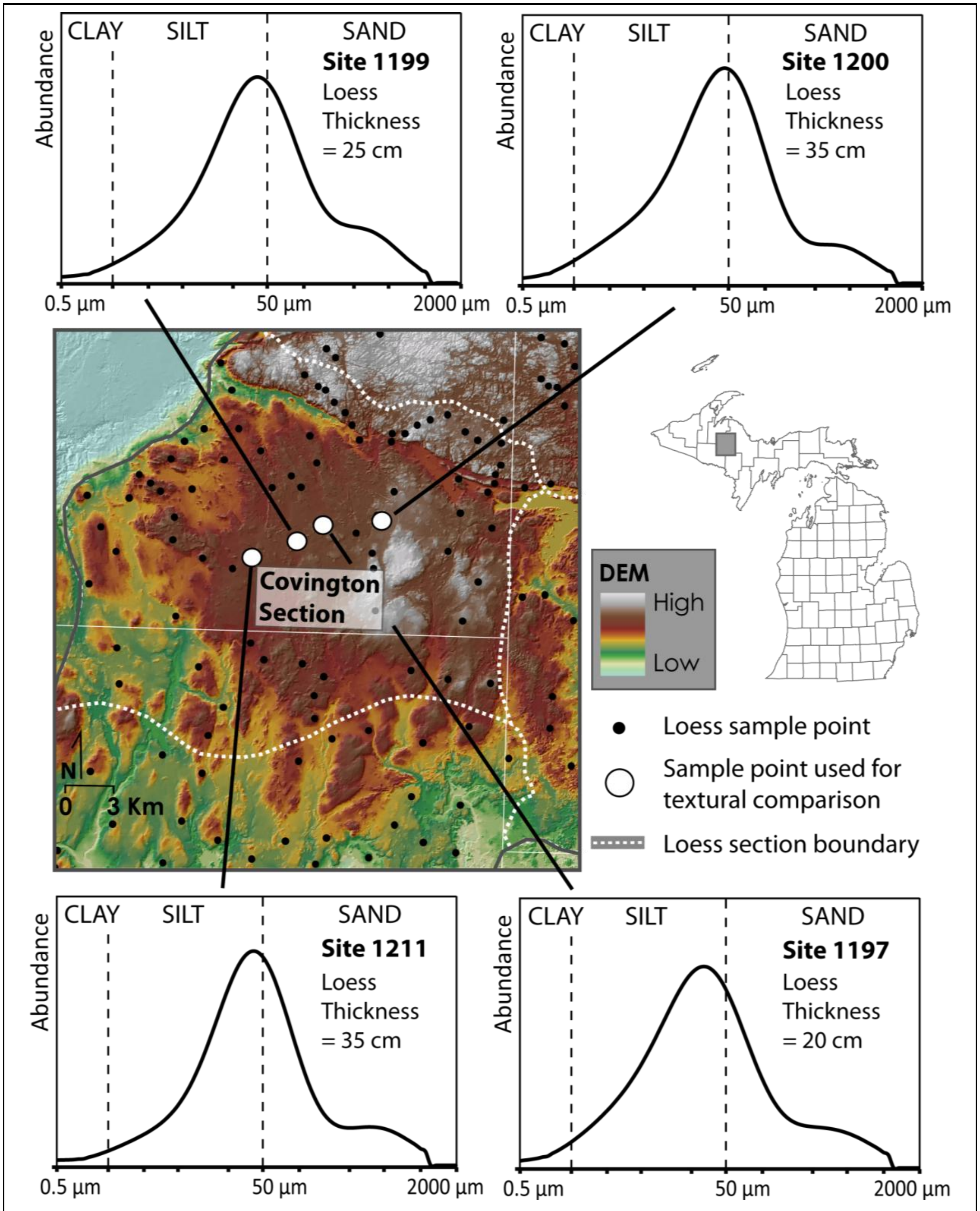


Figure 5.36: An example of four continuous textural curves from the Covington section. Note that the textural curves are very similar and all have a mode within the coarse silt fraction (35-50 µm).

Figures 5.17, 5.18, 5.19, 5.20, and 5.21 show that the Covington section may have a western source area because this region generally has high percentages of contents within the 25-75 µm fraction, compared to the surrounding areas. The Ontonagon Clay Plains is an extensive physiographic region (~200,000 hectares) ~ 12 km west of the Covington section (Figures 5.34 and 5.35; Peterson 1985; Schaetzl et al. (in prep.)) that is largely comprised of fine-textured tills and lacustrine sediments (Figure 5.37). Soils there have silt loam, silty clay loam, and clay loam surface textures, e.g., the Negwegon, Amnicon, and Cuttre series (Eversoll and Carey 2010). Generally the Ontonagon Clay Plains are a low to moderate relief landscape, but relief is much higher where the Ontonagon River and its tributaries have incised the landscape and created deep, V-shaped valleys (Figure 5.37). The dense network of steep and unstable slopes on the Ontonagon Clay Plains has exposed a plethora of fine-grained sediments. The Covington section's fine modal particle-size and the high percentage of contents within the 25-75 µm fraction, directly east of the Ontonagon Clay Plains, suggest that ~ 11,500 cal. yr BP, after the Marquette Phase (Hughes and Merry 1978; Lowell et al. 1999; Pregitzer et al. 2000), when vegetation was scarce, westerly winds likely deflated the fine-grained sediments from the Ontonagon Clay Plains and later deposited them on distant, stable-uplands, within the Covington section (Figure 5.35).

Additionally, a smaller and more local source area was likely the Baraga Plains, located east of the Ontonagon Clay Plains and adjacent to the Covington section (Figures 5.38 and 5.39). The Baraga Plains are a low relief, sandy, dry, outwash or glaciolacustrine plain. Similar to the Ontonagon Clay Plains, the Baraga Plains are likely associated with the Marquette Phase (Barrett et al. 1995; Arbogast and Packman 2004; Figures 5.16, 5.34 and 5.39;).The anomalously thick loess deposits of the Covington section, located directly east of the Baraga Plains, suggest that this small outwash plain (~ 7,000 hectares) could have also contributed fine-grained sediments to the loess deposits of the Covington section (Figures 5.38 and 5.39). Moreover, Arbogast and Packman (2004) documented active sand dunes ~ 7,800 cal. yr BP on the Baraga Plains. During this dune activation period, saltating eolian sand may have facilitated down-wind transportation of the finer-grained sediments, similar to the model Mason et al. (1999) described.

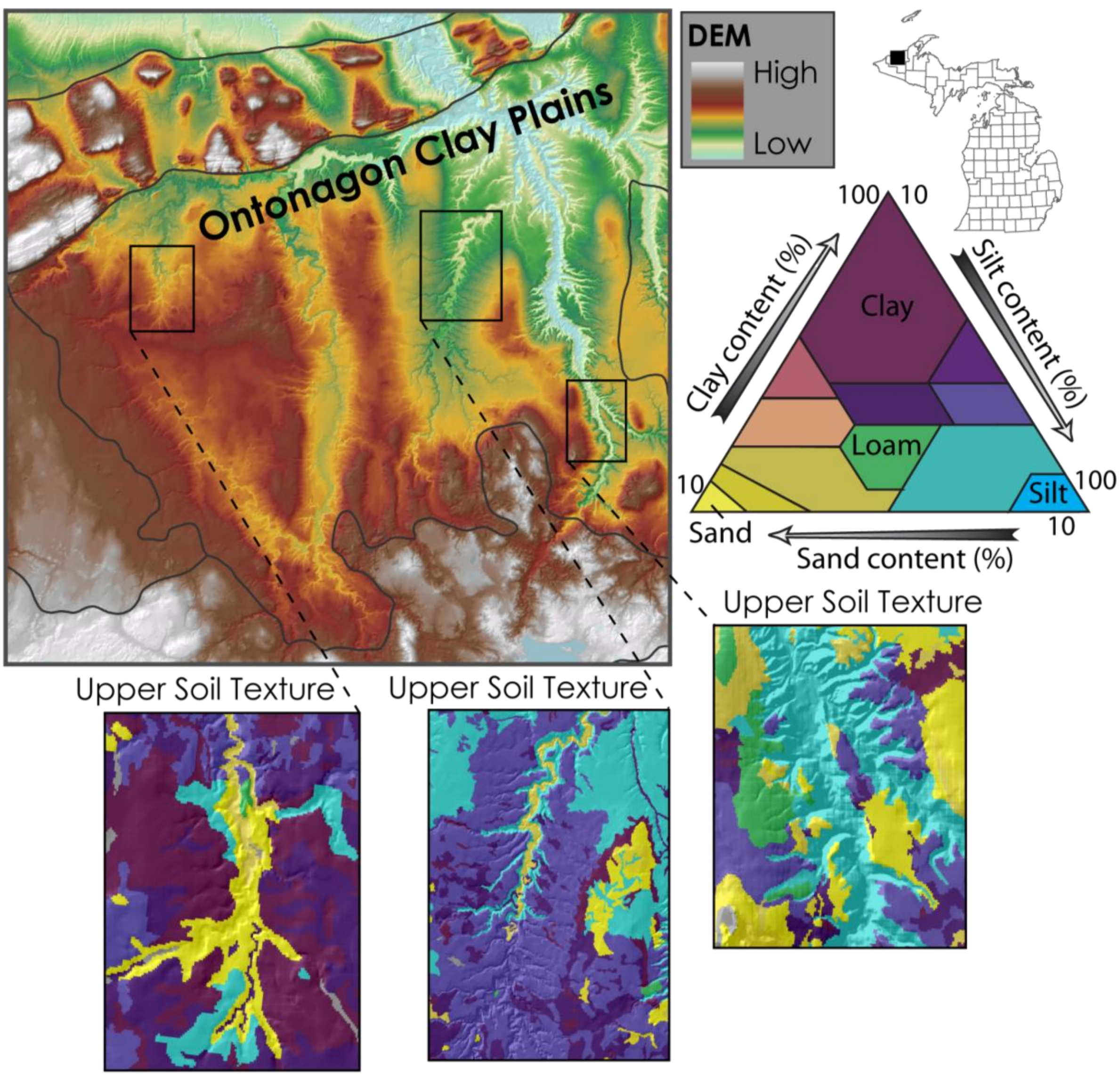


Figure 5.37: The unstable, deeply incised Ontonagon Clay Plains, showing V-shaped valleys and silt loam and clay loam upper soil textures.

This research suggests that the loess in the Covington section came from both distant and local sources. The Ontonagon Clay Plains were likely the dominant distant source area for the Covington section because of (1) the east-west, tongue-shaped distribution of silt contents within this area, and (2) the overall fine modal particle-size of this loess (Figure 5.35). Although it likely contributed less, the Baraga Plains could have also contributed fine-grained sediments to the Covington section due to the anomalously thicker loess deposits located directly southeast of the Baraga Plains (Figure 5.38).

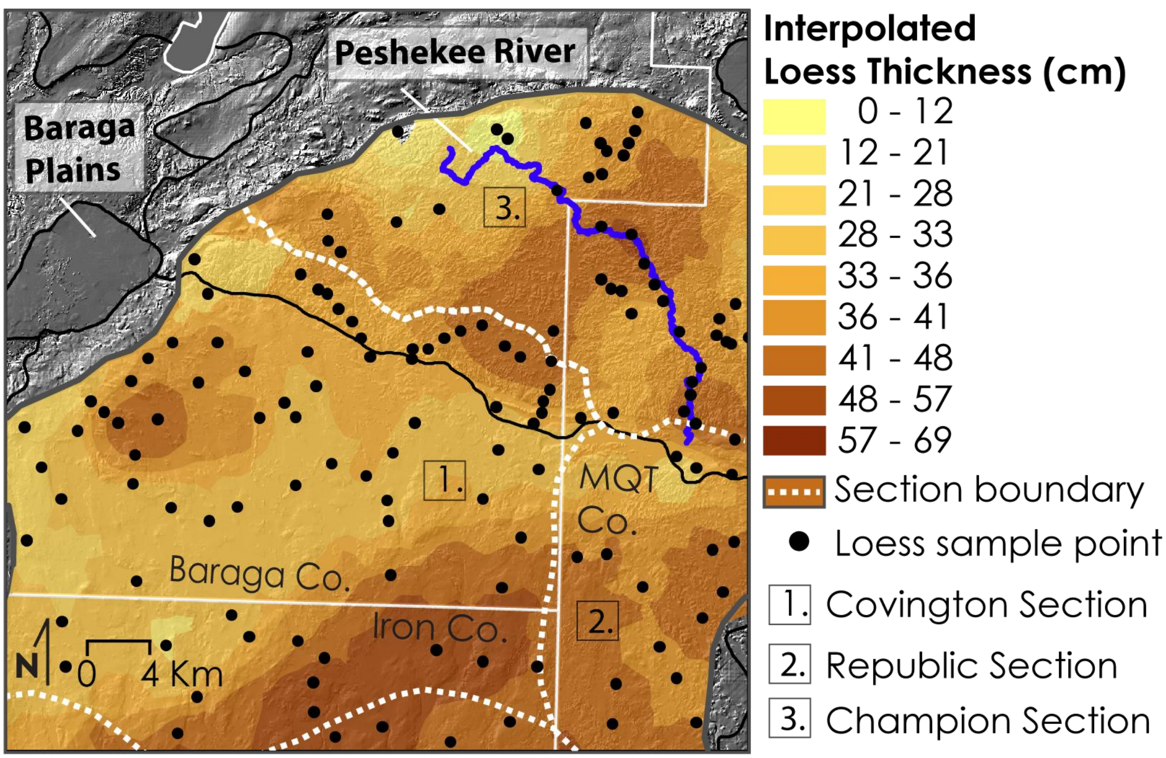


Figure 5.38: Map showing loess thicknesses and the anomalously thick loess deposits that are located within the Covington section, just southeast of the Baraga Plains.

Figure 5.39: The Baraga Plains, a low-relief outwash plain with scattered sand dunes. Photograph by R. Schaetzl.

5.4.3 Republic Section

The Republic section is located near the eastern and southeastern margins of the study area, in western Marquette County. Of the four loess sections in the study area, loess in the Republic section has the second highest mean thickness (42.5 ± 11.8 cm) and 25-75 µm fraction contents - 47.2 percent (Tables 5.7 and 5.8). The first and second most common ETC types within the Republic section are the type 2 and type 1 curves; ~ 53 percent of the samples collected in this section have a type 2 ETC and ~ 37 percent have a type 1 ETC (Table 5.7; Figure 5.40). Typical continuous textural curves from the Republic section show that loess deposits here usually have a high abundance of coarse silt (50 µm) and fine, very fine sand (50-75 µm), often with a small, secondary peak in medium sand (250-500 µm) fraction (Figure 5.40). The main attribute that distinguishes the Republic section from the Amasa section is the modal particle-size of the loess samples. The Republic section has a mean modal particle-size of 49.8 µm, whereas the loess in the Amasa section is much finer with a mean modal particle-size of 38.6 µm (Table 5.7). I suggest that the coarser-textured loess in the Republic section is due to more localized source area(s) composed of coarser sediments.

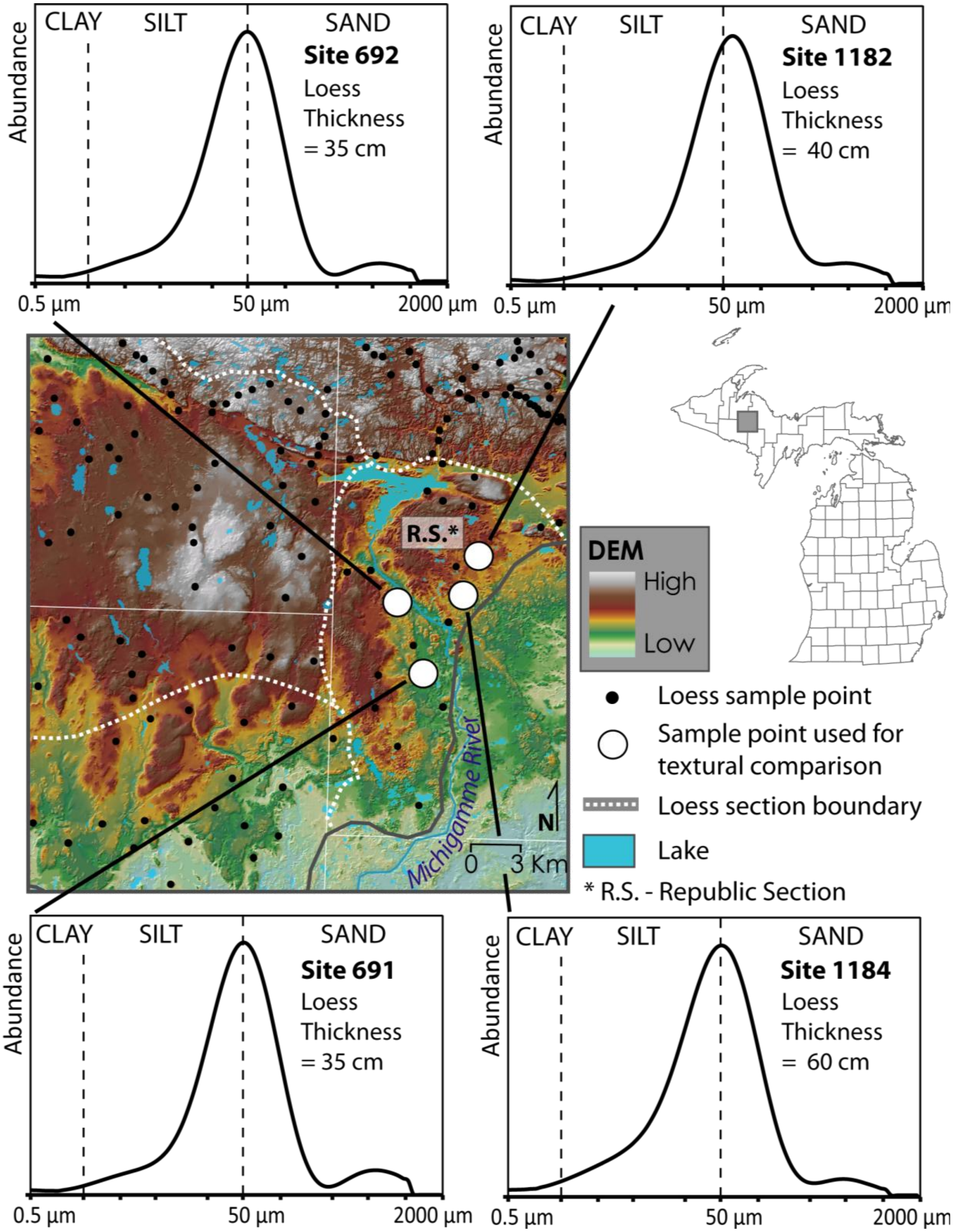


Figure 5.40: Examples of continuous textural curves from the Republic section. Note that the textural curves are very similar and all have a mode within the fine, very fine sand fraction (50-75 um).

The Michigamme River, Republic Moraine, Sagola Moraine, and the Gwinn Sandy Terrain are all near the central and eastern margins of the Republic section, and were likely local source areas for the loess in the Republic section (Figures 5.33, 5.34 and 5.40). The Michigamme River was likely carrying silt-rich, glacial meltwater while the Michigamme and Green Bay lobes stalled at the Republic and Sagola ice-margin positions. During low-flow events when discharge was minimal, the river's floodplain and terrace sediments would have been exposed. Strong, chaotic winds presumably could have deflated the fine-grained floodplain and terrace sediments and deposited them on adjacent stable-uplands within the Republic section.

Peterson (1986) describes the Republic Moraine as being composed of gravelly and sandy, brown till. He also suggested that the Sagola Moraine was built by the Green Bay Lobe and consists of calcareous red drift composed of ice-contact stratified sand and gravel (Figure 5.33). The red color of the till suggests that the ultimate source of the drift was the red Precambrian sandstones and shale from the Lake Superior basin (Attig et al. 1985; Peterson 1986). During the retreat of the Michigamme and Green Bay lobes from the Republic and Sagola ice-margin positions, strong, katabatic winds may have winnowed-out the fine-grained sediments from the coarse-textured glacial till (Figure 5.31; Bigsby 2010). These fine-grained sediments were then likely deposited within the Republic section, on near-by, stable-uplands, south of the Republic and Sagola moraines.

The Gwinn Sandy Terrain is located in central Marquette County, east of the Republic section, and may also have been a source area for the loess in the Republic section (Figures 5.34 and 5.35). The Gwinn Sandy Terrain is dominated by a sandy head-of-outwash, distal to the Watton ice-margin position (Figures 3.9 and 5.33). The topography of this region includes hummocky areas, incised stream valleys, small bedrock outcrops and bedrock-influenced terrain, and low, rolling terrain on sandy thick drift (Table 3.3; Schaetzl et al. (in prep.)). Again, strong, katabatic winds may have winnowed-out the fine-grained sediments from the coarser outwash and deposited them on adjacent, stable-uplands, as they did from the Vilas County Outwash Plains.

In sum, loess in the Republic section was probably generated from local source areas. Evidence for this conclusion is the coarser nature of the loess deposits (Figure 5.31). Nonetheless, this section likely had multiple source areas due to the thick loess deposits that exist there (Table 5.7; Figure 5.16).

5.4.4 Champion Section

The Champion section is the northern-most loess section within the study area. The Champion section is within the Peshekee Highlands physiographic region, where the relief is generally very high, in some places more than ~ 205 m per 250 m radius area, with an average of ~ 30 m. Conversely, the Michigamme Bedrock Terrain has an average local relief of ~ 13 m, and is where the Amasa, Covington, and Republic sections are located (Figures 3.8 and 5.28). Loess deposits in the Champion section are generally thinner and have a coarser modal particle-size than the Amasa, Covington, and Republic sections (Tables 5.7 and 5.8). The mean loess thickness for the Champion section is 32.9 ± 10.3 cm, whereas the Amasa, Covington, and Republic sections have mean thicknesses of ~ 52, 37, and 43 cm, respectively (Table 5.7). The Champion section's mean modal particle-size within the 26-99 µm fraction is 52.9 µm, compared to the Amasa, Covington, and Republic sections that have mean modal particle-size in the 26-99 µm fraction of 38.6, 40.2, and 49.8 µm, respectively (Table 5.7). Moreover, the loess deposits within the Champion section are generally much sandier than are the loess deposits of the Amasa, Covington, and Republic sections (Tables 5.7 and 5.8). The Champion section's mean content within the 250-500 µm fraction is 13.4 percent, whereas the mean 250-500 µm fraction content within the Amasa, Covington, and Republic sections are 9.9, 8.2, and 5.5 percent, respectively (Table 5.7). Type 2 and 4 ETCs are the most common ETCs for the Champion section, which has the lowest percentage of both type 1 and 2 curves, and the highest percentage of the type 5 and 3 ETCs (Table 5.7). Figure 5.41 shows that the continuous textural curves of loess deposits within this section generally vary considerably across even short distances, and that the modal particle-size of these loess deposits fluctuates around 50 µm. This is likely a product of these Champion loess deposits having several, small, local source areas. Thus, the modal particle-size will vary, in addition to the thicknesses, depending on distance and direction from the source areas.

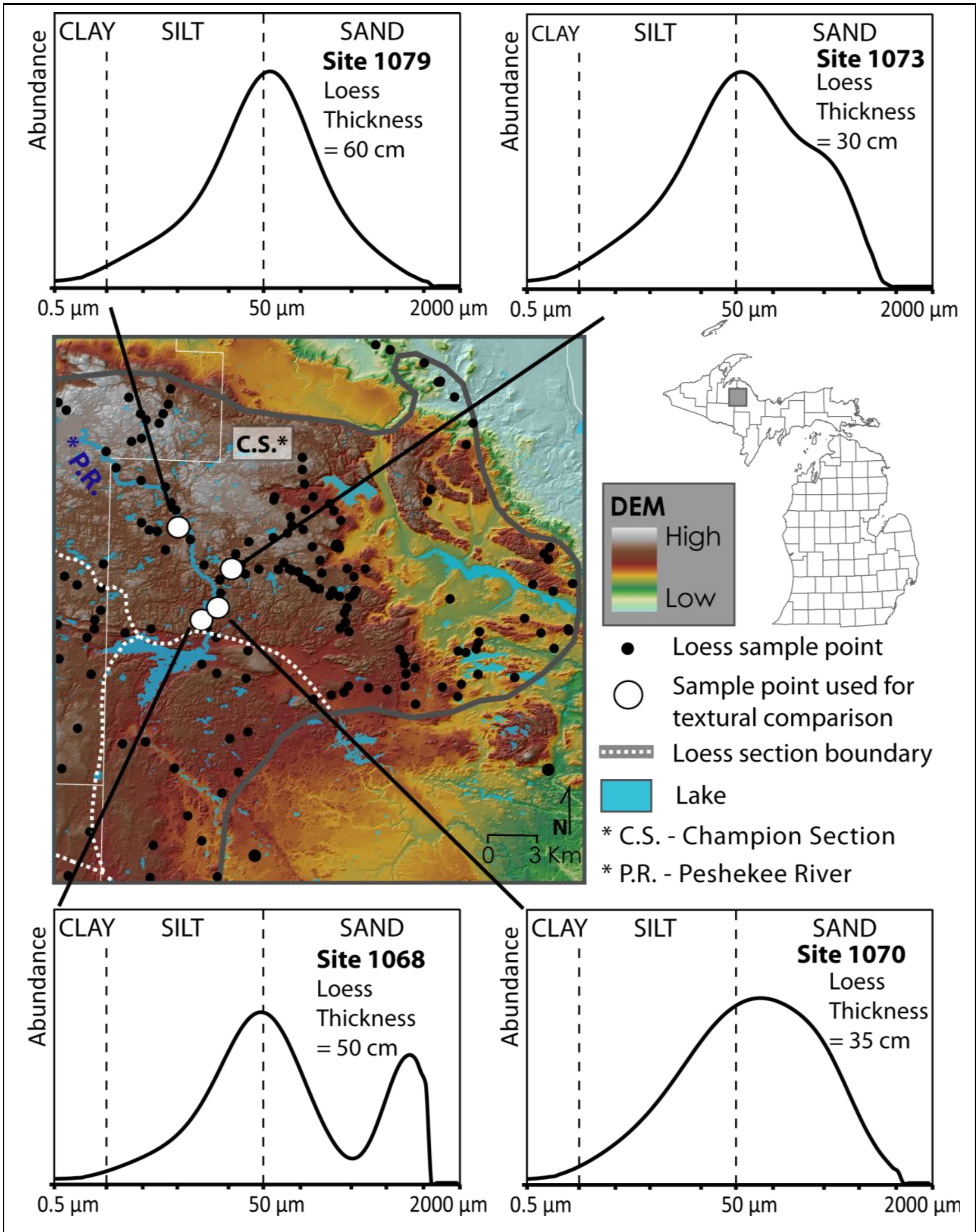


Figure 5.41: Examples of continuous textural curves from the Champion section. Note that the textural curves of loess deposits within this section generally vary considerably across short distances, and that the modal particle-size of these loess deposits is generally within the fine, very fine sand fraction (50-75 µm).

Loess within the 50-75 μm fraction, likely did not travel far, and thus, like the Republic section, the Champion section's loess deposits were presumably from local source areas. Small, interspersed glacial meltwater streams and outwash plains were likely the dominant sources of loess for the Champion loess deposits. The Peshekee River flows through the western part of the Champion section, and Figure 42 shows that there are several anomalously thick loess deposits located near the Peshekee River, which has been associated with the Marquette Advance (Hughes and Merry 1978; Farrand and Drexler 1985; Barrett et al. 1995; Lowell et al. 1999). When the Michigamme Lobe retreated north from the Marquette Phase, ice-marginal position, the stream presumably carried glacial meltwater, and was choked with both coarse- and fine-grained sediments. During low-flow events, the finer sediments would have been exposed on the river's floodplain and terraces (Figures 5.43 and 5.44). Eventually strong winds could have deflated the fine-grained sediments and deposited them on adjacent uplands within the Champion section (Figures 5.42 and 5.44; Schaetzl and Liebens 1992, 1993).

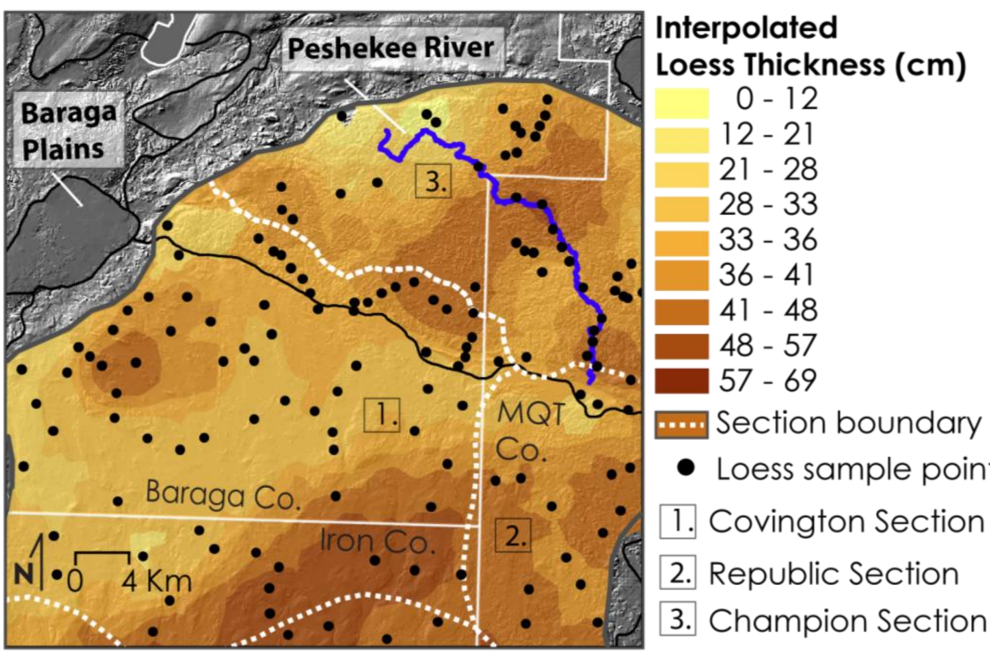


Figure 5.42: Map showing the anomalously thick loess deposits that are located near the Peshekee River, within the Champion section.

Figure 5.43: Peshekee River terrace and terrace sediments. Photograph by R. Schaetzl.

Figure 5.44: The Peshekee River - an underfit stream. Photograph by R. Schaetzl.

Moreover, small interspersed outwash plains were also likely source areas for the Champion section. Although the kriged maps of the distributions of loess thicknesses and silt contents do not provide evidence of this assertion, field observation and NRCS parent material maps show that there are numerous low-relief, sandy, outwash plains interspersed throughout the Peshekee Highlands and Champion section - generally in the areas between bedrock knobs (Figure 3.9). The coarse nature of the loess deposits within Champion section suggests that the loess did not travel far and was likely in suspension for a short period of time. The coarser and sandier outwash plains would have presumably been the first to dry-out and thus allow for strong winds to deflate the fine-grained sediments and later deposit them on near-by stable uplands. This region's high-relief and rugged topography did not allow for saltation to occur very far and hence, the very fine sands are likely from local source areas. Additionally, there is strong evidence of established vegetation prior to the Marquette advance - the Lake Gribben forest bed, near palmer in Marquette County (Lowell et al. 1999). Thus, the uplands within the Peshekee Highlands could have had small amounts of vegetation which may have acted as a trap/sink for fine-grained sediments that were being transported by wind.

5.5 Summary

The study area is an assemblage of several smaller, overlapping loess regions that likely had several heterogeneous source areas. Thus, loess textures and thicknesses usually vary between sections. The sections with thicker loess deposits are generally within the Michigamme Bedrock Terrain, and usually have a low percentage of sand. Conversely, the Champion section, which is within the Peshekee Highlands, generally has thinner loess deposits and these deposits are sandier.

6. Conclusions

Wind-blown silt has been recognized over a great deal of the central United States. In the core of the region, ranging from Illinois to Nebraska, loess deposits may exceed several meters in thickness and usually have one dominant source area, e.g., the Mississippi or Missouri River floodplain. At the distal edges of these large loess regions, the deposits are, generally, much thinner and are very discontinuous. Many argue that, in such areas, the loess may have been sourced from different areas and landforms. These thin loess deposits are also patchy and vary in texture from site to site.

Recent research demonstrates that loess deposits also occur in the upper Midwest. Prior work by Schaetzl and Hook (2008), Schaetzl and Loope (2008), Schaetzl (2008), Hobbs et al. (2011), Scull and Schaetzl (2011), and Stanley and Schaetzl (2011) provides evidence that loess extends into both Michigan and Wisconsin. Within Michigan, the Peshekee Loess is at the northeastern margin of the North American, midcontinent loess region. This research is the first to document both the extent and textural characteristics of loess situated at the extreme margins of a much larger and thicker, region of loess. Peshekee Loess is patchy, with marked variations in both landscape topography and loess characteristics. Because the Peshekee Loess is intermittent and highly variable in texture, a data set clean-up process was initiated for this study. Five eolian textural curve types were found to dominant the study area, and each sample was assigned to one of these specific textural categories. This categorization of eolian textural curve types is unique and has never before been done by other loess studies.

The Peshekee Loess deposits often have a bimodal continuous textural curve, usually with a primary modal particle-size within the 25-75 µm fraction and a secondary mode within the 250-500 µm fraction. “Shoulder” textural curves are also common with Peshekee Loess, and they are considered to be a hybrid between a true unimodal continuous textural curve and a bimodal textural curve. Generally, within the study area, where the loess is thick and the relief is moderate, e.g., the Michigamme Bedrock Terrain, or near the southern margins of the study area, loess deposits contain more silt, e.g., ETC types 1, 2, and 4. Conversely, loess deposits usually have a higher percentage of sand, e.g., ETC types 3 and 5, where they are thin and where relief is high, such as in the Peshekee Highlands. Findings from this research suggest that thinner loess deposits often have had more of the coarser, underlying sediment mixed into the loess column than have the thicker loess deposits. Further research is needed to confirm this hypothesis and determine the main vectors for this mixing.

Overall, within the study area, loess deposits are the thickest near the southern margins and progressively become thinner towards the northeast. Moreover, loess deposits with the finest modal particle-sizes are usually near the southern margins of the study area; coarser textured loess deposits are towards the northeast. Field observations and maps showing the distributions of eolian particle size fractions suggest that the study area is actually an amalgamation of several, smaller loess regions.

The Peshekee Loess likely had both distant and local source areas, and several different kinds of landforms and landscapes contributed eolian sediment. Because of the heterogeneous nature of these source areas and the various amounts of in-mixed sand, the study area was divided into four sections. From south to north they are the Amasa, Covington, Republic, and Champion sections. The loess deposits within the Amasa section are thick and silty, and are likely the distal part of the Iron County Loess, where loess deposits are generally thick and silty, and extend a larger area. The dominant source area for the Amasa section was likely from the south, e.g., the Vilas County Outwash Plains of Wisconsin. The loess deposits within the Covington section are generally thin, with high percentages of silt and low sand content. The dominant source area for these loess deposits was likely from the west, e.g., the Baraga Plains and the Ontonagon Clay Plains. The loess deposits within the Republic section are generally thick, with low percentages of sand. They have abundant coarse silt and fine, very fine sand. The Republic loess deposits generally have a coarser modal particle-size, compared to the Amasa and Covington sections. The dominant source areas for the Republic section were likely from both the north and east, e.g., the Republic and Sagola moraines, the Michigamme River floodplain, and the Gwinn Sandy Terrain. The Champion loess deposits, located within the Peshekee Highlands, are generally thin, highly discontinuous, and sandy. Local source areas were likely the dominant sources for this loess, e.g., small, interspersed glacial meltwater streams and outwash plains. The Peshekee River floodplain was also likely a main source area for the loess of the Champion section. This river would have carried glacial meltwater, choked with silt, and thus, could have contributed fine-grained sediments ~ 11,500 cal. yr BP, while the ice margin sat at the Marquette Moraine.

This research has two main conclusions: (1) it recognizes that thin loess deposits, on a recently glaciated landscape, may have several source areas, and (2) it documents the effects of mixing within thin loess deposits. This research also provides valuable insight into how to map and categorize thin loess deposits, near ice-margin positions. These thin loess deposits may provide important information on paleoenvironmental conditions during both glacial retreat and loess deposition.

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