Chapter 2

Sedimentology, chronostratigraphy, and facies relationships of fossiliferous sediments in the Upper Mississippi Valley, Minnesota and Wisconsin

ABSTRACT

Several distinct, fossiliferous lithofacies are preserved within the Upper Missippi Valley (UMV). These sediments show that several periglacial depositional mechanisms were active in this region throughout the late Pleistocene (ca. 24,000 to 16,000 cal. yr BP). Terrestrial gastropod shells are the most common fossils preserved in these sediments, but they have largely been overlooked for paleontological study. This paper describes the stratigraphic and chronologic relationships of ten fossiliferous outcrops in the UMV. The goals of this research are to: characterize fossiliferous lithofacies in the UMV, determine spatial and temporal relationships between outcrops, correlate these exposures to regional events, interpret the paleoenvironment around each site, and provide a brief report on the types of fossils commonly preserved within each section. This study will provide important context for future analyses (e.g. taphonomy) of these fossils. The typical distribution of lithofacies consists of clast- and matrix-supported diamictons along hillslopes that grade into laminated silts along the edges of the river valleys. Coarse, sandy lithofacies are commonly distributed closer to the valley axis. Radiocarbon data suggest that aggradation within river valleys was most active until about 19,000 cal. yr BP, and that hillslopes were active until at least 16,000 cal. yr BP. One site (Hideaway Lane) contained upstream dipping foresets and clay rip-up clasts characteristic of backflooding from the Mississippi River. The depth of erosion, sedimentary texture and composition are similar to backflooding deposits found elsewhere in the region. Ages from the Hideaway Lane exposure backflooding deposit do not correspond to known outburst flood events from upstream proglacial lakes. However, based on the timing (ca. 16,100 cal. yr BP) and lithology (red lacustrine clay), these may reflect drainage from either one or both of Glacial Lakes Lind and Duluth. Terrestrial gastropods were recovered from all lithofacies and were the most abundant fossils, whereas aquatic species were quite rare, comprising less than 5% of the total gastropod fauna. Most sediment was derived from local bedrock, and given the large proportion of terrestrial fossils within alluvium, terrestrial sediment input rather than glaciofluvial material was the dominant source of valley fill. This study provides important chronologic constraint on major aggradational and degradational phases within the UMV and demonstrates the importance of the gastropod fauna. Future paleontological studies in the UMV will need to consider these depositional contexts before attempting high-resolution paleoecological studies.

2.1 INTRODUCTION

Terrestrial gastropod shells are the most common fossils in late Pleistocene sediments throughout the Upper Mississippi Valley (UMV). Despite this, they have been largely overlooked as a tool for paleoenvironmental reconstruction. Previous studies have primarily focused on the geomorphology of the UMV, only using gastropod shells for radiocarbon dating (e.g. Mason and Knox, 1997). The periglacial sediments within the UMV contain a record of wind, gravity, and water-driven processes active during the last full-glacial period (ca. 24,000 to 18,000 cal. yr BP – all dates given as calibrated calendar years before present, unless otherwise noted). A general temporal framework for many of these sedimentary deposits has been developed (Knox, 1996; Mason and Knox, 1997; Bettis et al., 2008); however, the timing of significant episodes of aggradation and degradation of alluvial deposits within the UMV remains unclear (e.g. Knox, 1996; Knox, 2005). In addition, no specific attempts to place these fossil gastropods into a regional chronological and depositional context have been made since Chamberlin and Salisbury (1885). The temporal constraints on the nature of sedimentation in the UMV will determine the nature of the paleobiological data contained within the associated fossil assemblages and provide strategies for future sampling and survey efforts.

This paper describes the temporal and stratigraphic relationships of 10 fossiliferous exposures in the UMV, correlates these sites with regional events, and interprets the environments of deposition at each site. This depositional context will serve as the basis to evaluate the paleontological implications (e.g. taphonomy, paleoecology) of the fossils contained within these deposits. This work also provides important new radiocarbon and sedimentologic data that constrain the timing of aggradation and degradation within the UMV. The aims of this chapter are threefold: 1) characterize the fossiliferous lihtofacies exposed in the UMV, 2) determine the spatial and temporal associations of these lithofacies, and 3) interpret the environments of deposition at each site and correlate them with larger-scale events.

2.2 GEOLOGIC BACKGROUND

The study area is within the Upper Mississippi Valley (UMV) of southeastern Minnesota and Driftless Area of southwestern Wisconsin (Figure 2.1). Unlike much of the rest of Minnesota and Wisconsin, the last glacial advance (ca. 24,000-16,000 cal. yr BP) did not cover this region. However, earlier glacial advances covered southeastern Minnesota whereas the Driftless Area of Wisconsin remained ice-free throughout most or all of the Pleistocene (Mickelson et al., 1983; Hobbs, 1999; Syverson and Colgan, 2004). This unique landscape is characterized by bedrock-controlled topography with deep, narrow river valleys incised into the Paleozoic Plateau of Minnesota, Wisconsin, Iowa and Illinois (Syverson and Colgan, 2004). Based on magnetically reversed silts within the Bridgeport Terrace of the lower Wisconsin River, most of the valleys in the Driftless Area were eroded to their present depth before 780,000 yr BP (Knox and Attig, 1988).

Gently south-southwest dipping Cambrian and Ordovician bedrock underlies the entire region (Ostrom, 1987a, 1987b; Brown, 1988; Runkel, 1994). The oldest Cambrian units are exposed in the northern end of the study region. The oldest exposed section includes the coarse, orange arenitic sandstone of the Wonewoc Formation, which underlies the silty, micaceous, glauconitic sandstones and shales of the Lone Rock

Formation. The remaining Cambrian section, including the St. Lawrence and Jordan Formations, is generally covered. Throughout the UMV, Ordovician dolomites of the lower Prairie du Chien Group (Oneota) crop out as resistant bluff formers. The south end of the study region consists of the Prairie du Chien Group dolomites with occasional outcrops of uppermost Cambrian Jordan Sandstone along the lower reaches of larger valleys.

Along the UMV, ridgetops are covered with a thin mantle of windblown silt (loess), while the steep hillslopes are often covered by colluvium of increasing thickness downslope, where it grades into alluvial valley fill. Late Pleistocene eolian sediment, covers much of the North American Midcontinent. In Nebraska, the Peoria Silt is often more than 20 m thick; in Wisconsin it is only about 0.5-3 m thick (Hole et al., 1968; Leigh and Knox, 1994). Previous researchers have separated this loess deposition into several distinct periods (e.g. Busacca et al., 2004). Deposition of the Peoria Silt, the youngest and best-preserved loess unit in the Driftless Area began about 30,000 cal. yr BP and lasted until approximately 11,000 cal. yr BP (Bettis et al., 2003). Deposition of the Peoria Silt was not continuous, however. Weak paleosols are present in the Peoria Silt in Nebraska, Iowa, Illinois, and Indiana, indicating periods of little or no loess deposition (Ruhe et al., 1971; Bettis et al., 2003).

Thick colluvium covers many of the steep valley sides throughout the region, indicating active mass wasting along slopes. Based on radiocarbon and stratigraphic analyses, mass wasting was most active from 25,000 to 14,000 cal. yr BP as a result of climatically induced mass wasting, probably dominated by solifluction (Mason, 1995; Mason and Knox, 1997). This colluvium consists of reworked eolian silt and clay and often contains large clasts of weathered bedrock. Along the lower footslopes in the Driftless Area, colluvial deposits often interfinger with alluvial sediments within the river valleys (Mason, 1995; Mason and Knox, 1997). This interpretation conflicts with an earlier proposal by Black (1969) that hillslopes were largely stable throughout the Pleistocene, and that colluvial activity was the result of increased Holocene precipitation. Similarly, Mills and Delcourt (1991) suggested colluvial debris at the base of footslopes in the Appalachian Blue Ridge province were triggered by intense rainfall from increased tropical storm activity in the early Holocene. Colluvial activity would have contributed a large volume of material to the fluvial systems within the UMV, affecting both general sedimentation patterns and the types of fossils preserved in colluvial and alluvial sediments.

Alluvial sedimentation in the UMV is characterized by aggrading braided streams with high sediment bedloads (Knox, 1996). Aggradation within the UMV began by approximately 25,000 cal. yr BP and ended before 13,000 cal. yr BP (Flock, 1983; Knox, 1996). Much of the alluvial sediment is thought to be glaciofluvially derived (Flock, 1983; Knox, 1996). However, in river valleys not directly affected by glacial melt water, much of the valley fill consists of weathered bedrock and reworked silt and clay (Mason, 1995). Bettis and Halberg (1985) characterized the alluvial sediments in eastern Iowa as planar bedded, gray-silty clay and yellow-brown silt with rare red clay beds – a description that also applies to exposures in southeastern Minnesota and southwestern Wisconsin (Knox, 1996).

In many locations, the topmost late Pleistocene alluvial sediments consist of 30-50 cm of red clay and silt, which are interpreted as slackwater deposits from large flood events. Minor cut-and-fill deposits, characterized by sandy red clay and upstream-dipping foresets, can be seen along many tributaries in Wisconsin (Knox, 1996; Knox 2005). Following this period of valley aggradation, drainage of sediment-poor water from large glacial lakes cut into the late Pleistocene floodplain, creating a system of terraces throughout the UMV. Downcutting was likely completed by about 13,000 cal. yr BP when outburst floods from Glacial Lake Agassiz drained south via the Mississippi River for the last time (Knox, 1996). The highest terrace surface not covered by loess is referred to as the Savanna Terrace (Flock, 1983). This surface can be traced for more than 1,000 km along the length of the UMV from central Wisconsin to southern Illinois and several km upstream into major tributaries. Remnant high terrace surfaces can be followed from the Mississippi River into tributary valleys throughout the study region; therefore, I consider these tributary surfaces as part of the Savanna Terrace (*sensu* Mason, 1995).

2.3 METHODS

2.3.1 Field Methods

The locations discussed in this chapter (Figure 2.2) were discovered during field surveys in 2005 and 2006. I first identified potential outcrops from air photos and topographic maps, and located specific sites by driving systematically along highways looking for exposures of late Pleistocene sediments. I chose sites with abundant gastropod fossils, distinct sedimentary structures, and lithofacies characteristics for detailed study. I also reexamined sites mentioned by Mason (1995), who noted several gastropod-bearing exposures within the Root River Valley of Minnesota.

The location for each site was recorded using a handheld GPS and verified using air photos and digital elevation models available online from the USGS (http://seamless.usgs.gov). I also used these online maps to determine elevations of the Savanna Terrace, local tributaries, and Mississippi River near each location. I described a generalized stratigraphic column for each exposure to illustrate the vertical relationships between associated sedimentary lithofacies. In addition, I took photographs to illustrate the geographic context, horizontal relationships, and associations of prominent sedimentary structures. I used the “photomerge” function in Adobe Photoshop ® to assemble composite photographs of larger outcrops. These field observations, previous reports, airphotos, and digital elevation models were used to create an idealized cross section at selected time intervals.

I followed the lithofacies designations described by Miall (1977). This method designates major lithofacies groups with a capital letter followed by a lower case letter indicating unique sedimentary structures or other physical properties: e.g. “Fl” for fine-grained, laminated sediments; “Sp” for sandy, planar bedded sediments, etc. These designations are most often used for describing much older sediments, but are increasingly applied to Quaternary studies (e.g. Mason, 1995). The codes used to designate lithofacies described in this study are explained in Table 2.1.

My strategy was to differentiate between colluvial diamictons, sand-dominated, and silt-dominated lithofacies because they constituted the majority of sediment types in the study region. I subdivided these lithofacies based on associated sedimentary structures, but did not attempt to further differentiate these lithofacies based on smaller scale fabrics. Fine-grained **Silts (F)** contained less than 50% sand-sized grains. **Clays** were differentiated from silts by their smooth versus gritty texture and plastic behavior. **Sands (S)** were well to poorly sorted sediments containing at least 50% sand-sized particles. **Diamictons (D)** were poorly sorted and contained at least 10% pebble-sized or larger clasts (most often dolostone).

2.3.2 Lab Methods

For grain size analysis, I separated selected field samples into smaller ca. 100 g portions using a sample splitter. Clumps were either disaggregated by hand or gently crushed in a mortar and pestle to facilitate dry sieving. I used a sonic sifter and a standard series of sieves to determine the relative proportions of sand (2 mm – 0.063 mm) in each sample. For matrix processed to obtain fossils, I compared the mass of the wet-sieved residuum retained within the largest sieve (>2 mm) to the mass of sample that passed through all sieves (<0.425 mm).

I followed standard wet-sieve methods (e.g. Frest and Dickson, 1986) to recover fossils for analysis. Samples were first air-dried, then soaked for several hours to disaggregate the sediment. This material was washed through a series of ASTM sieves (smallest opening = 0.425 mm). Fossils were picked from the residuum and assigned to taxonomic group (terrestrial and aquatic gastropods, bivalves, fish scales, mammal teeth and bones, and ostracods) as present or absent from each sample/site.

2.3.3 Radiocarbon Analysis

I obtained radiocarbon dates from succineid gastropod shells. Succineid gastropods are abundant in many late Pleistocene deposits, and are often the only organic material available for radiocarbon dating (Pigati et al., 2004). There are two primary sources of error in radiocarbon dates obtained from gastropod shells. The first is recrystallization of aragonite to calcite, which can yield younger-than-actual ages. This error can be avoided by using shells without visibly recrystallized, “chalky” shell material and by pre-etching the sample in acid before analysis (Goodfriend and Stipp, 1983; Goodfriend and Hood, 1983). The second problem is harder to detect and occurs when the snail ingests ^{14}C-depleted carbonate, which can yield anomalously old radiocarbon ages (Goodfriend and Hood, 1983; Goodfriend and Stipp, 1983, Pigati et al., 2004). Succineid gastropods do not appear to ingest these “old” carbonates, even when in a ^{14}C-depleted carbonate environment (Pigati et al., 2004; J. Rech and J. Nekola personal communication, 2007). Radiocarbon ages were converted to calendar years using the “CalPal” online calibration software (Danzeglocke et al., 2009). Fossil material is cataloged in the University of Wisconsin-Madison Geology Museum under UW1987.

2.4 RESULTS

The data represent 10 sites within the UMV of Minnesota and Wisconsin (Figure 2.2). These sites are located both above and below the Savanna Terrace (Figure 2.3) and consist of both fine- and sandy-grained alluvial sediments and colluvial diamicts and silts (Figure 2.4). The results are presented in the following order: 1) general lithofacies descriptions for all of the sites studied; 2) grainsize characteristics for selected lithofacies; and 3) site-specific data including sedimentology, radiocarbon data, and observed fossils.

2.4.1 Lithofacies

The F, S, and D lithofacies observed at each site can be subdivided into individual lithofacies based on primary sedimentary structures (e.g. laminations, cross-bedding). All sediment samples from this study were calcareous and showed mild to strong effervescence with the addition of dilute HCl. Terrestrial gastropod fossils are preserved within all lithofacies, and were often the only biotic material recovered.

2.4.1.1 Fine-grained lithofacies (F)

Silt-dominated lithofacies in the study region consisted of poorly sorted, calcareous silt and clay with trace amounts of very fine to medium sand and pebble to cobble size clasts of local bedrock. Root traces and rhizocretions were common. Gastropod fossils were generally rare, however some samples contained more than 20 shells per kg.

Fl: Laminated silt. This lithofacies was characterized by alternating layers of reddish brown and buff to gray poorly sorted, calcareous silt and clay with occasional fine to medium sand. Root traces, halos, and rhizoconcretions are common. Where this lithofacies contacted bedrock, it often contained weathered, rounded to angular bedrock clasts. The Fl lithofacies was the most common lithofacies encountered below the Savanna Terrace. It also occurred along lower hillslopes above this terrace. Along valley floor margins, the Fl facies often interfingered with hillslope diamictons.

Fc: Convolute silt. This lithofacies can be differentiated from the laminated silts due to prominent soft sediment deformation structures, light gray color, and lack of internal lamination. Convoluted and slumped bedding, root casts, and vugs with iron oxide halos were common within this unit. The contact between this and other lithofacies was complex. The Fc unit contained irregular and sometimes overturned beds with apparent load casts or flame structures. Large (5-30 cm) clasts of underlying lithofacies were often incorporated within the convolute silt. Iron oxide bands were formed around these incorporated sediments.

Fm: Massive silt. Massive silts below the Savanna Terrace surface occur as 10-30 cm thick interbeds within laminated silts. Above the terrace at Big Platte, this massive silt consisted of dark brown silt with minor amounts of sand and angular dolomite bedrock fragments. Gastropod fossils were abundant within this lithofacies. Root traces and rhizocretions are also common. In outcrops, recent animal burrows (usually cliff swallow colonies) were most often found in the massive or thickly bedded silts compared to other sediments.

2.4.1.2 Sandy lithofacies (S)

Sand-dominated lithofacies contained abundant rounded lithic fragments and medium to fine grains of well-rounded quartz, glauconite, and muscovite. The texture and mineralogy of the sandy valley fill was nearly identical in composition to that of the local Cambrian-aged bedrock. The structures associated with these lithofacies were either **planar-bedded** with current and climbing ripples, or **trough-cross bedded** channel and channel fill bedforms. Gastropods were found throughout these lithofacies, especially in trough cross-bedded sands, where individual troughs contained several hundred shells per kg. In some troughs, gastropods formed shell-supported coquina-like beds within foresets.

Sp: Planar-bedded sand. This lithofacies consisted of poorly sorted gray to tan fine quartz sand with planar beds, as well as climbing and current rippled cross beds less than five centimeters in ripple height. It was most prominent at Kulas Quarry where it occurred in laterally continuous beds up to 1.5 m thick and more than 20 m wide. At other sites below the late Pleistocene terrace surface, thin 5-10 cm beds of the Sp lithofacies were interbedded within the laminated silts.

St: Trough cross-bedded sand. The trough cross-bedded lithofacies were exposed at Kulas Quarry and Hideaway Lane. This lithofacies was characterized by poorly sorted fine to medium grained, brown and tan sand with abundant rounded to well-rounded clasts of local bedrock. Bedrock clasts range in size from granules to cobbles and tabular clay rip-ups were less than 1 cm in diameter. Troughs ranged in size from 10 to 150 cm in height and fined upward from a coarse gravel lag at the base to fine grained sand at the top. Some troughs were filled with current and climbing ripple cross beds, while others were filled with massive fine sand to silt. At Kulas Quarry, the troughs were bound by laterally accreting foresets.

2.4.1.3 Diamict lithofacies (D)

Diamictons were either **clast-supported** or **matrix-supported**. In general, the diamictons were poorly sorted with silty tan to brown matrix and angular, gravel to boulder size clasts of dolomite bedrock. Most large clasts were oriented with the long axis parallel to slope. Gastropod fossils occurred within both lithofacies; other biotic material and root traces were rare or absent. Contacts between diamictons and other lithofacies were approximately parallel to slope. Along slopes near the valley floor, these diamictons interfingered with alluvial sediments and often were lenticular in cross-section.

Dm: Matrix-supported Diamictons. This lithofacies consisted of brown to tan silt with minor amounts of angular bedrock clasts. Bedrock clasts were predominantly dolomite, with some chert or sandstone, depending on location. This lithofacies was often found well above the Savanna Terrace surface (Figure 2.4). Below the terrace at Root River, the Dm lithofacies was interbedded with the laminated silts. Terrestrial gastropod fossils were common within this unit, and abundance exceeded 100 shells per kg. Occasionally, unbroken gastropod eggs and root traces such as rhizocretions were encountered within this lithofacies.

Dc: Clast-supported Diamictons. Clast-supported diamictons were mineralogically similar to matrix-supported diamictons, but differed in the proportion of large clasts. Fossils and root traces were generally rare within this lithofacies, although gastropod fossils were sometimes preserved within the interstitial matrix of even the coarsest diamictons.

2.4.2 Grain Size Analysis

In addition to the expected differences between sandy and silty sediments, grain size analyses of selected samples showed that the trough cross-bedded sands (St) were coarser than the planar-bedded sands (Sp). The St lithofacies contained a larger proportion of coarse sand and pebble-sized clasts compared to the Sp samples (Figure 2.5). Within silt-dominated sediments, the laminated silt (Fl) lithofacies were similar to one another, while the convolute silt (Fc) lithofacies from Kulas Quarry was finer, and contained a much smaller proportion of sand-sized material.

2.4.3 Sites

The locations of the sites described in this study are shown in Figure 2.2, Figure 2.3 and described in Table 2.2. The radiocarbon age data from each site are shown in Figure 2.4 and summarized in Table 2.3. These sites covered an area approximately 200 km North-South and 50 km East-West. Five sections (Kulas Quarry, Kulas-2, Kulas-1, Hwy-JJ, and JX) were described from the Latch Valley, a small tributary valley of the Trempealeau River. Two sections (Storer Creek and Root River) were described along the Root River in Minnesota. The remaining sections were located along tributary valleys in southern Wisconsin: Coon Creek (Hideaway Lane), Limery Creek (Limery Coulee), and the Platte River (Big Platte). Three of these sites (Hwy-JJ, Limery Coulee, Big Platte) were located along hillslopes above the Savanna Terrace, while the rest were located within the paleo-floodplain at or below this surface (Figure 2.3, Figure 2.4).

2.4.3.1 Kulas Quarry

Kulas Quarry is a large borrow pit approximately 7 m high by 21 m wide, located in the Latch Valley (Figure 2.6A). The top of this exposure correlates with the Savanna Terrace. Much of the Kulas Quarry section consisted of either trough cross-bedded (St) or planar-bedded (Sp) sands (Figure 2.6B). A prominent scour surface is visible along the base of the upper St lithofacies, separating the exposure into two individual fining upward packages of sediment (Figure 2.4; Figure 2.6A). The upper meter consists of laminated silt (Fl) that was weathered down to about 50 cm. Numerous fish scales, vertebrate teeth and post-cranial bones were present throughout the exposure, often within discrete, fossiliferous lenses or as plaster deposits along foreset surfaces within St lithofacies. Terrestrial gastropod shells were abundant; individual samples contained as many as 500 shells per kg of sediment. Aquatic gastropods were present, but much less common than terrestrial shells. Rare, disarticulated valves of bivalves and ostracods were also recovered. Succineid gastropod shell material (ca. 3 shells of *Catinella* cf. *gelida*) from the trough-bedded sand (KQ-15) 2.75 m below the top of the exposure yielded radiocarbon ages of 16,670±60 RCYBP (BETA-223641; 19,929±295 cal. yr BP). An additional sample (ca. 3 shells of *Catinella* cf. *gelida*; KQ-05) 4.5 m below the exposure surface yielded an age of 17,550±70 RCYBP (BETA-223642; 20,961±314 cal. yr BP). Charcoal and additional *Catinella* c.f. *gelida* shells from these two horizons were analyzed by Jason Rech et al. (in prep):

- KQ-15 (depth = 2.75 m)
    - Shell: 16,840±120 (AA-83090; 20,059±296 cal yr BP)
    - Shell: 16,890±120 (AA-83092; 20,122±288 cal yr BP)
    - Shell: 17,180±130 (AA-83091; 20,617±330 cal yr BP)
    - Charcoal: 31,400±120 (AA-77831; 35,310±362 cal yr BP)
- KQ-05 (depth = 4.5 m)
    - Shell: 17,990±200 (AA-82558; 21,673±448 cal yr BP)
    - Charcoal: 28,720±320 (AA-82587; 33,190±478 cal yr BP)

These shells yielded similar dates to those analyzed by Beta Analytic, Inc within the same horizon, however the charcoal is likely reworked, since radiocarbon results from these small wood samples were much older than the shell dates.

2.4.3.2 Kulas-1 and Kulas-2

Kulas-1 and Kulas-2 were located within the Latch Valley, about 500 m downstream from Kulas Quarry (Figure 2.7A). These exposures were less than 250 m apart and are described together. The top of the exposure at Kulas-2 correlated to the Savanna Terrace, while the top of the exposed section at Kulas-1 was approximately 3 m lower. Both exposures were dominated by laminated silt lithofacies. A few thin beds of planar-bedded sand occurred near the base of Kulas-1. Other root traces such as rhizocretions and root haloes were present at both Kulas-1 and Kulas-2. Numerous 0.5-1 m long vertical cracks were exposed at Kulas-1. These probably represent root traces due to the downturned laminae and bifurcation of these wedge-shaped features (Figure 2.7B). Ice wedges create upturned laminae of the surrounding sediment as the ice expands and forces the sediments upward and outward (e.g. Clayton et al., 2001).

Two 20 cm thick layers of dark brown, clay-rich sediment were present at each site, approximately 1 m below the top of both exposures. These beds were not correlative with each other. Based on the dark color, cementation, clayey texture, and lateral continuity, these horizons may represent weakly developed paleosols or early pedogenic textures. Samples of laminated silt from both Kulas-1 and Kulas-2 contained terrestrial and aquatic gastropod fossils. Interestingly, despite being located along the valley floor, these sections did not contain large channel features or other evidence of active fluvial transport apart from small 5-10 cm thick tabular cross-bedded sands and silts. This finding contrasts with Kulas Quarry, where large trough beds are visible throughout the exposure.

2.4.3.3 Hwy-JJ

Hwy-JJ was a 3 m tall scarp exposure of laminated silt located along a footslope within the Latch Valley, approximately 1 km downstream from Kulas Quarry (Figure 2.8). The base of this exposure was approximately 2.5 m above the Savanna Terrace surface. The Fl lithofacies exposed at this site contained millimeter-scale tan to buff silt and interbedded sub-millimeter red clay bands. These laminations were oriented parallel to the slope of the surface. Root traces and rhizocretions were common throughout the exposure. Weathered bedrock clasts were increasingly abundant near the base of this exposure, but the concentration of large clasts was less than 5%. Hwy-JJ samples contained terrestrial gastropod fossils. Three shells of *Catinella* c.f. *gelida* from a sample approximately 2 m below the top of the exposure yielded an age of 16,120±60 RCYBP (BETA-243248; 19,236±236 cal. yr BP). Terrestrial gastropod fossils were common throughout this exposure, along with occasional gastropod eggs.

2.4.3.4 JX

JX is a 3.6 m roadcut exposure of laminated tan silt with interbedded sand and massive silt, located at the mouth of the Latch Valley (Figure 2.9A). The top of the exposed section at JX was approximately at the same elevation as the Savanna Terrace. Rare gravel-sized clasts of sandstone bedrock and several thin, planar sand horizons are present at the base of the section. About 100 m to the East, the Fl lithofacies can be observed lying disconformably atop the Cambrian Wonewoc Formation (Figure 2.9B) The section fines upward into laminated silt with a thin 20 cm soil horizon developed at the top of the exposure. Root traces and rhizocretions were increasingly abundant towards the top of the exposure. Samples from JX contained both aquatic and terrestrial gastropod shells.

2.4.3.5 Storer Creek

Storer Creek is a 10.7 m tall by 200 m wide roadcut exposure of tan to buff, laminated silt in the Root River Valley, Houston County, Minnesota (Figure 2.10). The top of this exposure correlated to the Savanna Terrace. Shells of *Catinella* cf. *gelida* 2.5 m below the top of this exposure yielded an age of 15,800±50 RCYBP (Beta-223643;

19,019±221 cal. yr BP). Sandy trough cross-beds were exposed near the base of the section. Small rhizocretions were encountered throughout the exposure. Several samples contained abundant terrestrial gastropod shells, but few shells of aquatic taxa. Two samples did not yield gastropod shells, but did contain numerous ostracod valves.

2.4.3.6 Root River

Root River is a 4-7 m tall roadcut exposure of laminated silt and interbedded, clast-supported diamicton located approximately 5 km downstream from the Storer Creek section (Figure 2.11). This section was studied by Mason (1995) and data published by Mason and Knox (1997) provided ages of 15,983±136 RCYBP (AA-17787; 19,140±238 cal. yr BP) 1 m below the top of the exposure, and 16,925±351 RCYBP (AA-17786; 20,256±543 cal. yr BP) 5 m below the top of the section. Both of these dates were obtained from gastropod shells. The types of snails were not recorded, although *Catinella* cf. *gelida* or *Discus shimeki* were the most likely species analyzed (J. Mason personal communication, 2005). Both aquatic and terrestrial gastropods were recovered from this locality.

2.4.3.7 Hideaway Lane

Hideaway Lane is located approximately 20 km south of La Crosse, Wisconsin in the Coon Valley, Vernon County, Wisconsin (Figure 2.12A). This small roadcut exposure consisted of 80 cm of cross-bedded sand and silt with abundant red and gray clay rip-up clasts. Gastropod shells and shell fragments were also common. The thinly bedded foresets at Hideaway Lane were approximately 50 cm high, with an upstream dip direction (Figure 2.12B). The upper sediments at this location were covered. The elevation of the exposed St lithofacies was about 7 m below the high terrace, which may correlate to the younger Bagley Terrace (Knox, 2005), which is about 10 m lower than the Savanna Terrace. About 20 cm of massive, tan to gray silty clay is exposed below the St unit. The contact between these units is irregular, but distinct. Both aquatic and terrestrial gastropod species were abundant with occasional disarticulated bivalves and ostracods. A few badly eroded rodent teeth were also recovered. Two individual shells of *Succinea* cf. *bakeri* from the lower 20 cm yielded ages of 13,180±40 RCYBP (Beta-223640; 16,106±387 cal. yr BP) and 13,780±40 RCYBP (Beta-223639; 16,959±147 cal. yr BP).

2.4.3.8 Limery Coulee

Limery Coulee is located approximately 10 km north of the city of Prairie du Chien in Clayton County, Wisconsin (Figure 2.13). This 5.3 m tall exposure of clast- and matrix-supported diamicton was located on a steep hillslope more than 40 m above the Savanna Terrace Surface. Clasts consisted of large angular fragments of cherty, dolomite bedrock. The contacts between lithofacies and the orientation of the long-axis of larger bedrock clasts were roughly parallel to the slope. Few rhizocretions or root traces were found, but samples of the matrix-supported diamicton contained abundant terrestrial gastropod fossils and unbroken gastropod eggs. Shells of *Catinella* cf. *gelida* 1.3 m below the top of the exposure yielded an age of 13,460±50 RCYBP (Beta-243247; 16,415±409 cal. yr BP), while shells 40 cm below this sample yielded an age of 13,430±70 RCYBP (Beta-242905; 16,377±416 cal. yr BP).

2.4.3.9 Big Platte

Big Platte was a 1.5 m tall by 4 m wide scarp exposure of massive silt in the Platte River valley of southwestern Grant County, Wisconsin (Figure 2.14). Bulk samples from throughout this exposure contained abundant terrestrial gastropod fossils and gastropod eggs. A thin 20 cm thick bed of barren, massive sand outcropped below the fossiliferous Fm lithofacies and below this, a massive sandy silt contained rare terrestrial gastropod shells. Individual shells of *Succinea* cf. *bakeri* yielded ages of 15,710±60 (Beta-223638; 18,964±228 cal. yr BP) and 15,890±50 RCYBP (Beta-223637; 19,075±215 cal. yr BP) from approximately 30 cm below the top of the exposure. A shell of *Succinea* cf. *bakeri* from 65 cm below the top of the section yielded an age of 15,800±100 RCYBP (Beta-231781; 19,021±229 cal. yr BP). Large, spherical rhizocretions 2-3 cm in diameter were abundant throughout the Fm lithofacies at Big Platte. The contact between the sand and silt was roughly parallel to bedding, but no distinct sedimentary structures were observed at this location.

2.5 DISCUSSION

2.5.1 Depositional Environment

Figure 2.15 represents a generalized cross section showing the relationships between the lithofacies described above. The relationships are based on the observations from this study as well as data presented by Mason (1995), Knox (1996), and Mason and Knox (1997). The colluvial diamictons mantle the hillslopes, thickening downslope where they laterally grade into the silty lithofacies. Silty lithofacies are concentrated along lower footslopes (as colluvium) and valley edges (reworked colluvium or distal floodplain sediments), while the sandy lithofacies deposited within the active channel belt occupy the central valley fill.

Both the clast-supported (Dc) and matrix-supported (Dm) diamictons are indicative of gravity-driven colluvial deposits, based on the location of these sediments along hillslopes and the slope-parallel orientation of large clasts. Massive and laminated silts above the Savanna Terrace are likely colluvial or reworked colluvial deposits. The absence of root traces and rhizocretions within the Dm and Dc lithofacies suggests little well-established vegetation atop these deposits. Radiocarbon age data from sites in this study suggest downslope movement of sediment was active between 19,000 and 16,000 cal. yr BP. These dates agree with the findings of Mason and Knox (1997), who suggested permafrost-induced solifluction was active between 25,000 and 13,000 cal. yr BP. The presence of unbroken gastropod eggs suggests that movement of these lithofacies may have been relatively slow and gradual or large blocks of colluvium remained intact during transport; higher energy mechanisms would likely have crushed these fragile fossils.

Based on the location of the silt-dominated lithofacies along the edges of valley floodplains and presence of aquatic and terrestrial gastropod species within these lithofacies, laminated silts are primarily a result of alluvial sedimentation outside the active river channels either as slackwater deposits or reworked colluvial and eolian silt. The presence of root traces and rhizocretions suggests that these sediments were sufficiently stable and exposed to allow extensive vegetation to develop. Root traces at Kulas-1 are up to 50 cm in length suggesting some of these plants possessed a long, well-developed root system. In addition, the dark brown clay-rich horizons at Kulas-1 and Kulas-2 suggest sufficient subaerial exposure to create a weathering profile. Flame structures and other fluid escape features at sites such as Kulas-1 suggest that some of the silt deposition was rapid, but the low amplitude cross stratification indicates relatively small sheet floods. Some of these soft sediment deformation structures are capped by more clay-rich sediment characteristic of slackwater deposits. The presence of aquatic gastropods and ostracods indicates that some of these areas retained sufficient moisture to support aquatic animals, perhaps as seasonal ponds adjacent to the active floodplain. However, the well developed root traces and thin clay-rich horizons argue against numerous large, permanent pools. Hwy-JJ is located above the Savanna Terrace and probably represents distal gravity-driven silts and slopewash marginal to the floodplain. This interpretation is supported by the presence of small angular bedrock fragments, slope-parallel laminations and lack of aquatic gastropods.

The sand-dominated lithofacies at Kulas Quarry are characteristic of a braided stream depositional environment with trough cross-bedded channel and braid bar deposits within the active channels and thin, planar cross-bedded sands typical of overbank and splay deposits. Alternately, these deposits from a simple, rather than complex, network of braided streams. The active channel belt was relatively narrow; the width of the thickest trough cross-bedded sand lithofacies at Kulas Quarry is less than 10 m wide. The sediments at Kulas Quarry show two well-developed fining-upward architectural successions (Figure 2.4; Figure 2.7A). These sandy lithofacies represent a complex succssion of coarse, laterally accreting trough cross-bedded sands capped by thin, vertically accreting planar sands and silts. Lower trough cross-bedded sands (St) transition upward into planar-bedded sands (Sp), which are then covered by convolute silt (Fc). This fining upward pattern is characteristic of active channel migration away from the section exposure. Finer-grained overbank sediments are deposited atop these channel sediments. Loess was probably deposited on the inactive floodplain during this hiatus. The large proportion of silt and clay-sized sediment within the Fc lithofacies compared to laminated silts supports the interpretation of an eolian origin for these sediments (Figure 2.5). When the active channel belt returned to the Kulas Quarry exposure, the underlying fine sediments were partially scoured. Large clasts of intact St lithofacies occur within the Fc lithofacies. Irregular lobes of convolute silt have intruded into the overlying trough cross-bedded sands, apparently following bedding surfaces in some locations, suggesting the silt was "injected" into the overlying sands under pressure (Figure 2.6C). Deformation of the Fc lithofacies could be a result of cryoturbation and/or deformation by the weight of the overlying sands deposited as the active channel belt migrated back into the Kulas Quarry location.

The cross-bedded sand at Hideaway Lane is likely a result of backflooding from the Mississippi River. The large foresets, abundant clay rip-ups, and shell fragments are characteristic of high-energy flood deposits. The foreset height (ca. 30 – 50cm), incision depth (> 7 m), and abundance of red and gray clay rip-up clasts are similar to descriptions of backflooding deposits found elsewhere in the UMV such as Sandy Creek and Mill Coulee (Knox, 1996). At Onalaska, Wisconsin, about 22 km north of Hideaway Lane, a basal peat beneath a large cut-and-fill exposure on the Bagley Terrace yielded an age of 16,506±399 cal. yr BP (13,545±85 RCYBP, AA-23384; Knox, 2005). The ages from gastropod shells at Hideaway Lane closely match this observation. The relative stratigraphic position and radiocarbon data indicate that the incision and backflooding at Hideaway Lane occurred by approximately 16,100 yr BP, as the youngest dated shell must already have been formed before this flooding event occurred. These cut and fill features have been interpreted as a result of outburst floods from proglacial lakes further north (Flock, 1983; Knox, 1996; Knox, 2005). The red clay is characteristic of lacustrine clays from the Lake Superior Basin draining south along the Bois Brule and St. Croix Rivers (Flock, 1983; Knox, 1996; Figure 2.1). It is possible these sites are coeval, or reflect a general period of minor cutting and filling along the UMV floodplain prior to the final incision.

2.5.2 Chronology of events in the UMV

Based on the results of this study, multiple transport and depositional mechanisms were responsible for accumulating abundant gastropod fossils within the UMV between 22,000 and 16,000 cal. yr BP. Colluvial diamictons along hillslopes represent gravity-driven sediments moving downslope and grade laterally into alluvial sediments. Alluvial sediments consist of either silt-dominated lithofacies along valley margins that represent lower energy floodplains, or sand-dominated lithofacies along valley centers representing higher energy active channel belts within a braided stream environment (Figure 2.15).

Colluvial activity appears to have been active until at least 16,400 cal. yr BP, based on the radiocarbon data from Limery Coulee (Figure 2.4; Table 2.2). This agrees with the results of Mason (1995) and Mason and Knox (1997), who suggested hillslope sedimentation was a result of permafrost-induced solifluction.

Most of the valley aggradation occurred before 17,000 cal. yr BP based on the numerous ages within a few meters of the terrace surface that are clustered between 19,000 to 20,000 cal. yr BP (Kulas Quarry, Storer Creek, Root River; Figure 2.3; Table 2.2). Mason and Knox (1997) reported two radiocarbon dates between 17,300 and 18,000 cal yr BP (14,090±60, Beta-82840; and 14,650±210 RCYBP, Beta-82841) from wood within fluvial sediment about 4.5 m below the Savanna Terrace in Crystal Creek, a tributary of the Root River. Knox (2005) observed a gastropod shell lag beneath red clay-rich silt, about 4 m below the Savanna Terrace at Boice Creek in southwestern Wisconsin, which yielded an age of approximately 17,500 cal. yr BP (14,300±80 RCYBP; Beta-92064). Cutting and filling into the late Pleistocene surface is recorded at locations such as Hideaway Lane (see also Knox, 1996; Knox, 2005), with upstream dipping foresets in an exposure of cross-bedded, red clay-rich sandy silt. It is not clear if the high terrace surface is directly correlative with the Savanna Terrace at this location, as the younger Bagley Terrace complex is a prominent intermediate terrace surface along this stretch of the Mississippi River. The Bagley Terrace north of Hideaway Lane is a few meters lower in elevation, however, this terrace surface is quite variable (Knox, 1996) and Hideaway Lane may correspond to one of these intermediate surfaces. The radiocarbon data from Onalaska and Hideaway Lane suggests incision was underway by 16,500 cal. yr BP.

The red clay rip ups at Hideaway Lane are characteristic of lacustrine clay derived from the Lake Superior Basin via the St. Croix River Valley (Flock, 1983). Radiocarbon ages from Hideaway Lane and Onalaska predate the formation of Glacial Lakes Grantsburg and Agassiz (e.g. Johnson and Halmstead, 1998; Fisher, 2004). Knox (2005) suggested these flood deposits did not correspond directly to well-documented de-glaciation events, but instead were from Glacial Lake Duluth. Another possibility is Glacial Lake Lind. Although it is relatively small, Johnson et al. (1999) noted convolute bedding within the lacustrine silt and sands of Lake Lind characteristic of rapid drops in water level. The backflooding events preserved at Hideaway Lane and elsewhere may represent periodic, low-magnitude outbursts from the Lake Superior Basin. In northeast Iowa, incision of the late Pleistocene floodplain was completed by approximately 15,000 cal. yr BP, based on a radiocarbon age from wood within tributary valley sediment fill below the Savanna Terrace (Bettis and Hallberg, 1985). Between approximately 14,000 and 12,700 cal. yr BP, outburst floods from Lake Agassiz into the UMV likely contributed to downcutting, although the latest floods from this lake did not overtop the Savanna Terrace surface or backflood into tributary valleys (Knox, 1996; Fisher, 2004). The sediment bypass that characterizes the last phase of downcutting contrasts with the initial flooding events that left numerous backflood and slackwater deposits throughout the UMV.

During the aggradational phase, most sediment input to the UMV has been thought to be glacial in origin (e.g. Flock, 1983; Knox, 1996). However, the sections below the Savanna Terrace within the Latch Valley (Figure 2.1) consist almost entirely of weathered bedrock and do not show any influence of glaciofluvially-derived sediment. There are no backflooding structures or red clay sediments, and the observed sedimentary structures indicate downstream and lateral flow. The lack of extrabasinal sediment within the Latch Valley is probably due in part to the protected nature of the Trempealeau River drainage basin. Glaciofluvial outwash sediment would have been directed either to the north along the Chippewa River, or to the south, via the Black River (Figure 2.1). In addition, Mason (1995) noted the lack of backflooding or glaciofluvial sediment within the Root River Valley and suggested alluvial sediment consisted of weathered bedrock and reworked loess as a result of terrestrial input from permafrost induced mass wasting of hillslope material. The lack of backflooding evidence in some tributaries may relate to the dynamics of the tributary system or simply because of erosion.

The influence of terrestrial sediment input on valley aggradation is supported by the presence of bedrock-derived sediment throughout exposures in the Latch and Root River Valleys. In the Latch Valley, the radiocarbon dates are separated by 1,000 years and approximately 2 m of sediment. Assuming the total valley is about 10 km^2 and the middle of the valley is filled with sediment (about 25% of the total area; fill volume = 2 m * 2500 m^2 = 5000 m^3), it would require a 67 cm-thick layer of material from the sides of the valley to fill the center with 2 m of material (5000m^3 ÷ 7500m^2 = 0.67 m). This suggests a hillslope erosion rate of approximately 0.6 mm/yr. In addition, terrestrial gastropods are the dominant fossil remains at all sites; aquatic gastropods account for less than 5% of the total number of shells obtained from any location (Table 2.2). In addition to the rates of erosion and sedimentation, assuming a constant lateral migration rate for the Latch Valley creek channel belt, and that the succession exposed at Kulas Quarry represents one complete back and forth cycle across the valley (2 * 400 m) yields a lateral migration rate of approximately 0.8 m/yr.

2.5.3 Conclusions and implications for future work

Despite being underutilized for more than 100 years (Chamberlin and Salisbury, 1885), the gastropod fauna from late Pleistocene sediments in the UMV shows tremendous potential for future paleoenvironmental studies. It is not the intent of this study to explain the complex dynamics of the entire Mississippi River/Laurentide glacial meltwater system, but by outlining the temporal constraints on the dominant sedimentary mechanisms and depositional characteristics found within the UMV, it is possible to discuss the potential implications of these results and suggest avenues for future work.

Based on stratigraphic and radiocarbon age data from the sections described in this study, deposition of fossiliferous sediments in the UMV began before 22,000 yr BP and continued throughout the late-glacial period, approximately 16,000 yr BP. These findings agree with those of Mason (1995), Knox (1996), and Mason and Knox (1997). What is interesting to note is that many of the fossiliferous deposits immediately below the Savanna Terrace are roughly synchronous, generally none is older than 22,000 cal. yr BP and none is younger than 16,000 cal. yr BP. These dates are well before major climatic shifts, such as the Younger Dryas or Mid Holocene thermal maximum. Studies into the response of biotic groups to large climate changes will benefit from locating younger deposits (such as younger, intermediate terraces or along the modern floodplain) to establish a longer local chronologic record. Alternately, the contemporaneous nature of these deposits offers the possibility of studying latitudinal environmental gradients during the last full-glacial period (ca. 24,000 to 18,000 cal. yr BP).

While aggradation dominated the depositional characteristics of sediments below the Savanna Terrace, cutting and filling from outburst flooding events suggests the potential for mixing shells of disparate ages and locations. Care should be taken to characterize the age structure (see Chapter 4) of faunas within locations. For example, based on the sedimentary characteristics, unbroken gastropod eggs, and overlapping radiocarbon ages, it may be reasonable to assume that little age-mixing has occurred within the massive silt at Big Platte (Figure 2.4; Figure 2.14). However, given the mechanics of backflood deposition and widely separated radiocarbon results, it would be problematic to assume less than a thousand years age difference between shells preserved within the deposit at Hideaway Lane (Figure 2.4; Figure 2.12).

The dominance of terrestrial gastropods in all sediment samples indicates a high proportion of terrestrial sediment input. Sources such as weathered bedrock and loess were likely brought down into valleys via solifluction or other gravity-driven mechanisms. This has implications for local, gastropod-based environmental interpretations due to the potential to mix similarly aged taxa with widely differing habitat preferences as sediments travel downslope and into the stream valleys. Sites deposited during periods of high stream velocity such as Kulas Quarry and Hideaway Lane present the possibility of hydrodynamically sorted assemblages, with easily transported shells separated from less mobile forms. In addition, compaction of fine, clay rich sediment will tend to crush fragile shells more than coarse sediments. Groundwater movement through sandy sediments may allow for a higher degree of oxidation and diagenetic alteration compared to silt and clay rich lithofacies.

Finally, the potential for gastropods to inform future studies related to the dynamics of UMV aggradation and degradation cannot be understated. Gastropods are often the only organic material preserved within these sediments and they have proved invaluable in establishing a regional radiocarbon chronology for major sedimentary episodes within the UMV. Multiple shell radiocarbon dates from discrete horizons often overlap within one sigma, whereas the minute charcoal fragments are significantly older suggesting that reworked charcoal may persist within the environment for much longer periods (e.g. Figures 2.4, 2.6A). The inverted ages of the charcoal may reflect gradual “unroofing” of the surrounding basin soils and infilling of the basin. When coupled with other techniques such as optically stimulated luminescence (OSL) or amino acid racemization (AAR), it might be possible to further constrain the principal sedimentary episodes within smaller-order tributaries. Data from the Latch Valley suggests weathered bedrock was an important source of sediment in the Driftless Area during the aggradational phase of the UMV. This aggradational phase has preserved a rich, but underutilized fossil assemblage from a dynamic periglacial environment.

2.6 ACKNOWLEDGEMENTS

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Table 2.1. Lithofacies codes used in this study.

Facies descriptions	
Fm	Massive Silt
Fl	Laminated Silt
Fc	Convolute Silt
St	Troug cross-bedded Sand
Sp	Planar bedded Sand
Sm	Massive Sand
Dc	Clast-supported Diamicton
Dm	Matrix-supported Diamicton

Table 2.2. Location, elevation, and fossil types at sites discussed in text. Note: aquatic gastropods represent less than 5% of the total number of shells recovered in any sample.

Site	Lat	Lon	Terrace	Elev (m)	Ht (m)	F	Sh/Kg	N	TG	AG	BV	OS	FS	RT
Kulas Quarry (KQ)	44.1731	-91.5483	0	231.6	7.4	Sp, St	79.7	21	x	x	x	x	x	x
Kulas-2 (K2)	44.1693	-91.5454	0	231.6	2.5	Fl	NA		x	x				
Kulas-1 (K1)	44.1687	-91.5427	-3.4	231.6	4	Fl	NA		x	x				
Hwy-JJ (JJ)	44.168	-91.5573	4.1	235.7	2.5	Fl	17.7	8	x					
JX	44.1564	-91.5542	0	227.3	3.3	Fl	NA		x	x				
Storer Creek (SC)	43.7918	-91.4233	0	219.5	10.7	Fl	19.1	5	x	x		x		
Root River (RR)	43.787	-91.4831	-2.5	217	7	Fl	35.8	2	x	x				
Hideaway Lane (HL)	43.6664	-91.1978	-6.9	206.5	0.8	St	NA		x	x	x			x
Limery Coulee (LC)	43.0888	-91.1155	49.5	258.3	5.3	Dm	192.1	2	x					
Big Platte (BP)	42.6944	-90.6433	13.7	211.8	1.5	Fm	49.4	20	x					

Notes: "Terrace" = Elevation of section top relative to late Pleistocene terrace surface; "Elev" = height of section top above sea level; "Ht(m)" = height of measured section; "F" = Facies present in section; "Sh/Kg" = Average no. shells per Kg of sample matrix; "N" = no. of samples; "TG" = Terrestrial gastropods; "AG" = Aquatic gastropods; "BV" = Bivalves; "OS" = Ostracodes; "FS" = Fish Scales; "RT" = Rodent Teeth

Table 2.3. Radiocarbon and calibrated age data for sites from this study. Note the discordance between shell and charcoal (char) radiocarbon results.

Site	Lab#	14C Age	Cal Age	Depth (m)
Kulas Quarry	Beta-223641	16,670±60	19,929±295	2.75
Kulas Quarry**	AA-83090	16,840±120	20,059±296	2.75
Kulas Quarry**	AA-83091	17,180±130	20,617±330	2.75
Kulas Quarry**	AA-83092	16,890±120	20,122±288	2.75
Kulas Quarry**	AA-77831(char)	31,400±120	35,310±362	2.75
Kulas Quarry	Beta-223642	17,550±70	20,961±314	4.5
Kulas Quarry**	AA-82558	17,990±200	21,673±448	4.5
Kulas Quarry**	AA-82587(char)	28,720±320	33,190±478	4.5
Hwy-JJ	Beta-243248	16,120±60	19,236±236	2
Storer Creek	Beta-223643	15,800±50	19,019±221	1.5
Root River*	AA-17787	15,983±136	19,140±238	1
Root River*	AA-17786	16,925±351	20,256±543	4
Hideaway Lane	Beta-223639	13,780±40	16,959±147	0.6
Hideaway Lane	Beta-223640	13,180±40	16,106±387	0.6
Limery Coulee	Beta-243247	13,460±50	16,415±409	1.7
Limery Coulee	Beta-242905	13,430±70	16,377±416	2.5
Big Platte	Beta-223638	15,710±60	18,964±228	0.2-0.5
Big Platte	Beta-223637	15,890±50	19,075±215	0.2-0.5
Big Platte	Beta-231781	15,800±100	19,021±229	0.7

Notes: "**Depth (m)**" indicates depth below top of section where ^{14}C date obtained; all dates obtained via AMS ^{14}C analysis of gastropod shell carbonate unless noted; site locations shown in Figure 1; radiocarbon calibration via c**alpal online**; *dates from Mason and Knox (1997); **dates from Rech et al. (in prep).

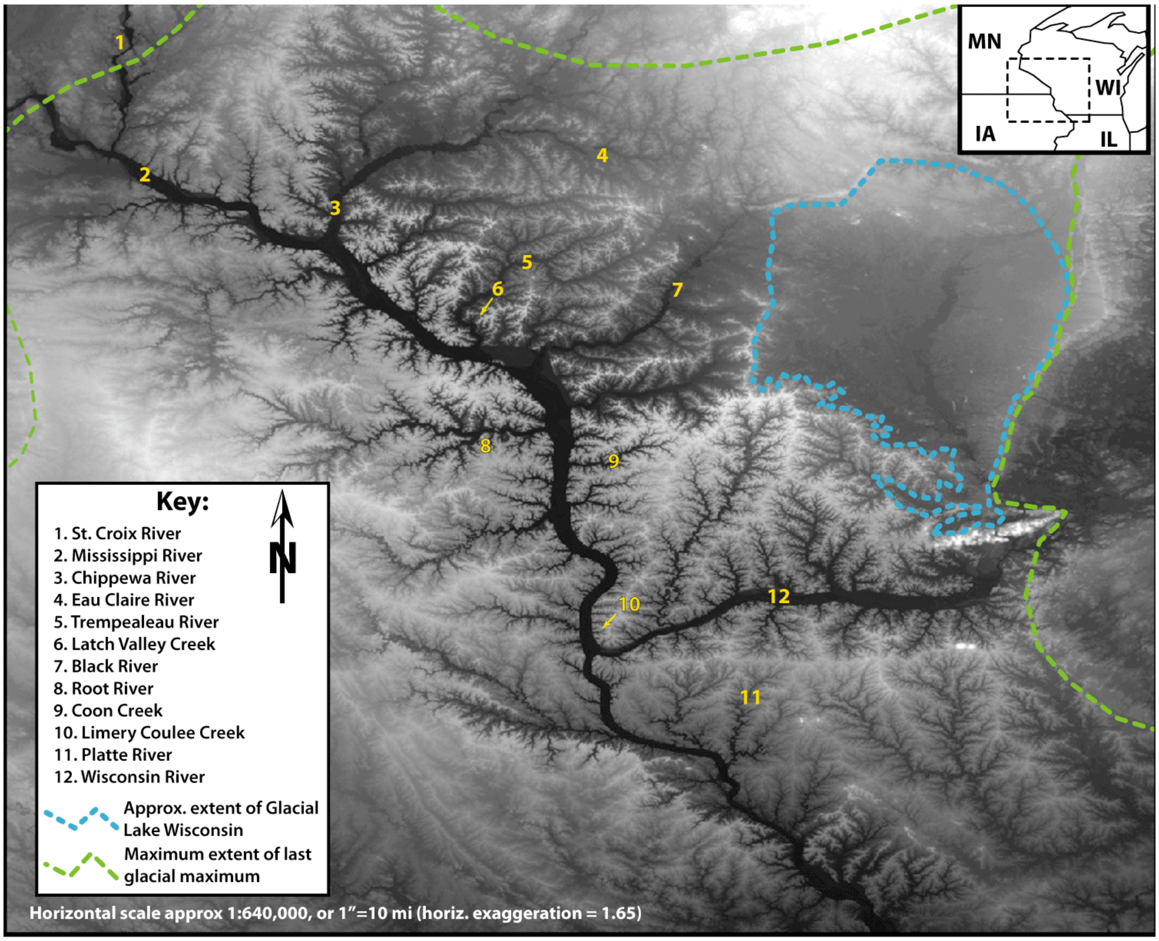

Figure 2.1 Shaded (white=high elevation) relief map of the study region. Primary tributaries and sites discussed in the text are indicated.

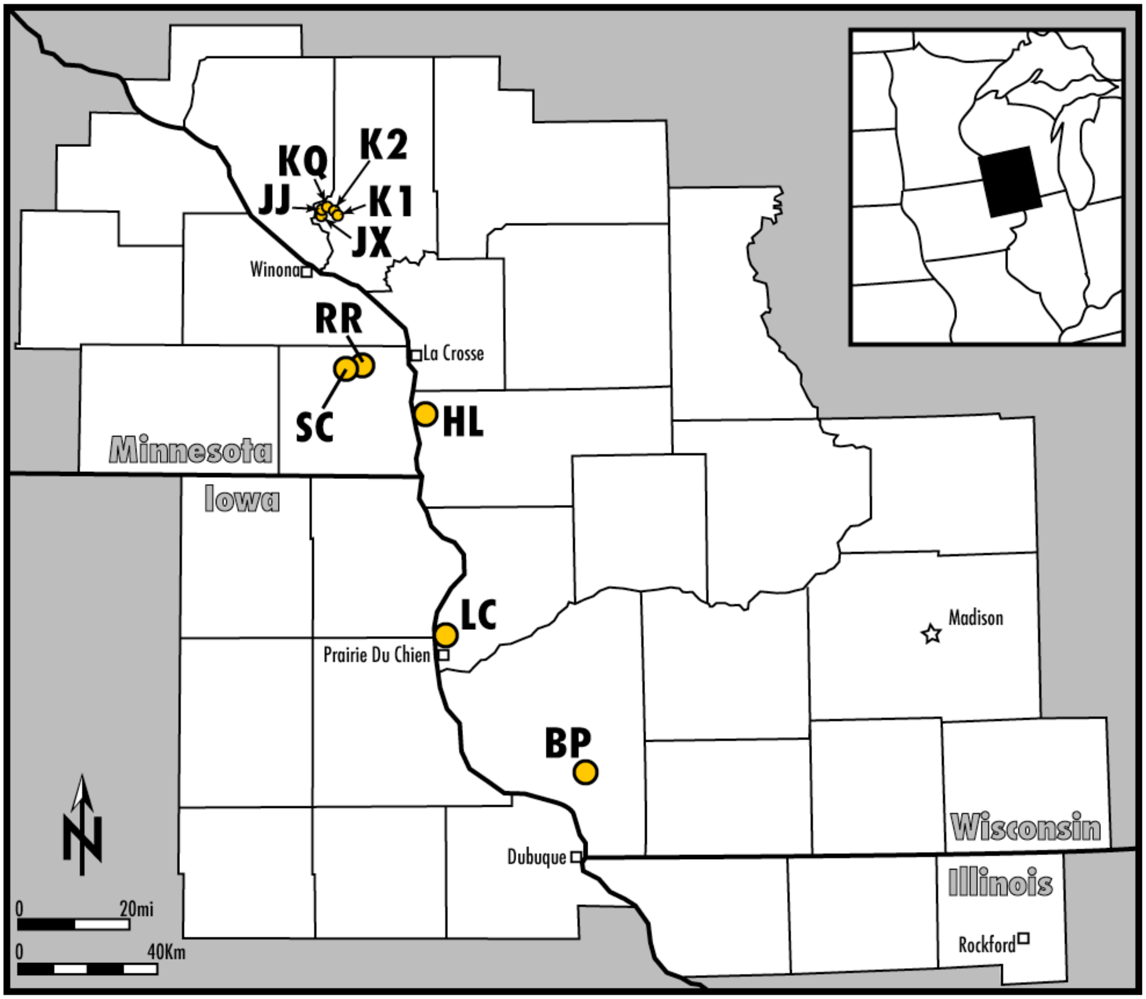

Figure 2.2 Locations of sites discussed in this chapter. KQ=Kulas Quarry, K1=Kulas-1, K2=Kulas-2, JJ=Hwy-JJ, RR=Root River, SC=Storer Creek, HL=Hideaway Lane, LC=Limery Coulee, BP=Big Platte.

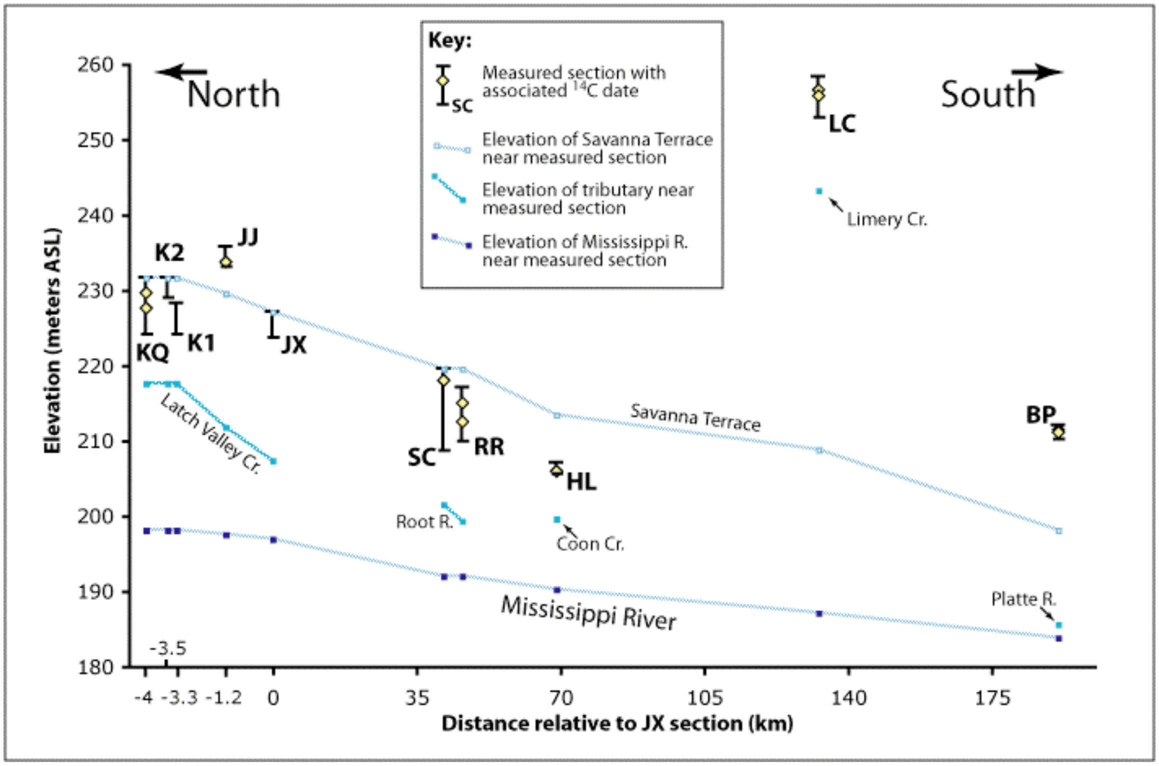

Figure 2.3. Locations of study sites relative to Savanna Terrace and modern stream surfaces. Note: horizontal distances between Latch Valley sections are exaggerated 10x for clarity. See Figures 2.1 and 2.2 for location information. The slope break of the Savanna Terrace at Hideaway Lane (HL) is likely exaggerated due to the proximity of the younger, intermediate Bagley Terrace complex near this location.

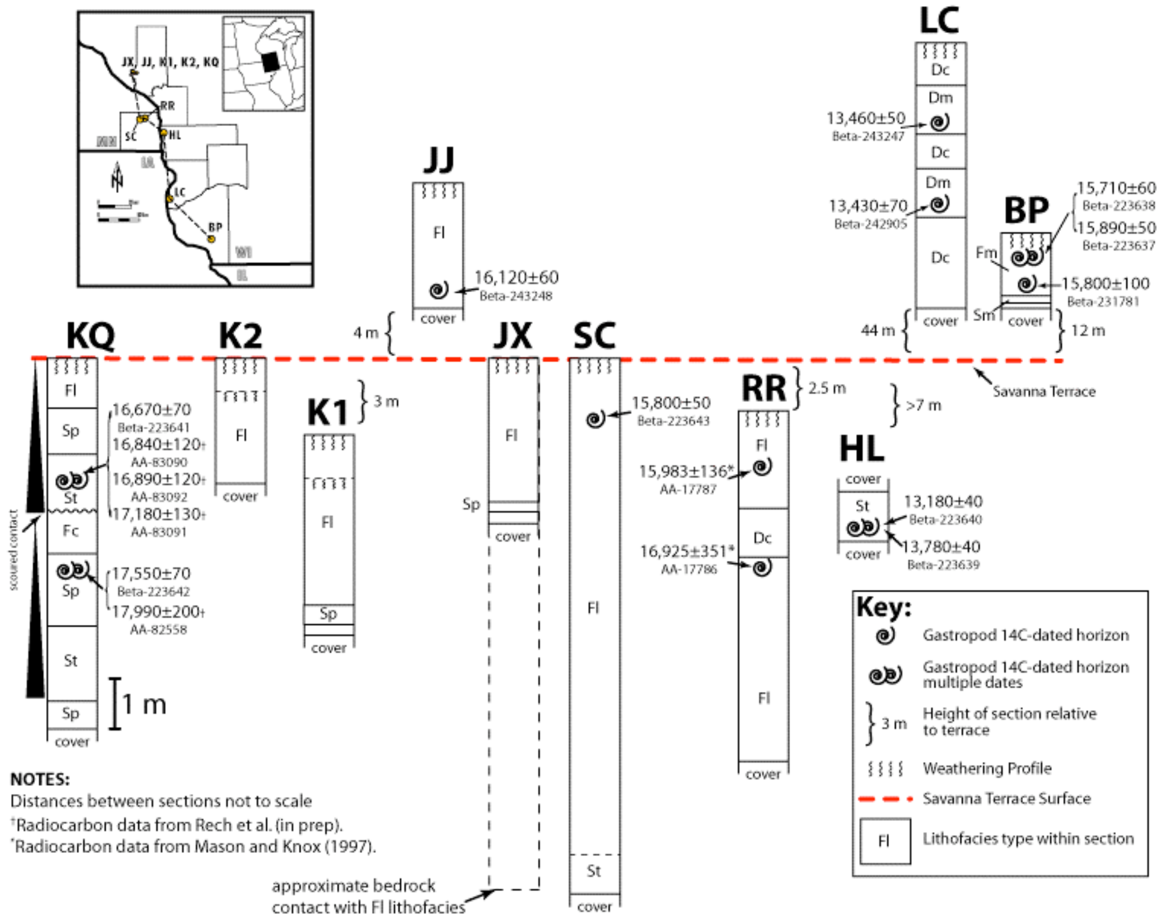

Figure 2.4. Stratigraphic sections described in text. KQ = Kulas Quarry, K2 = Kulas-2, K1 = Kulas-1, JJ = Hwy-JJ, SC = Storer Creek, RR = Root River ("Lehman" in Mason and Knox, 1997), HL = Hideaway Lane, LC = Limery Coulee, BP = Big Platte.

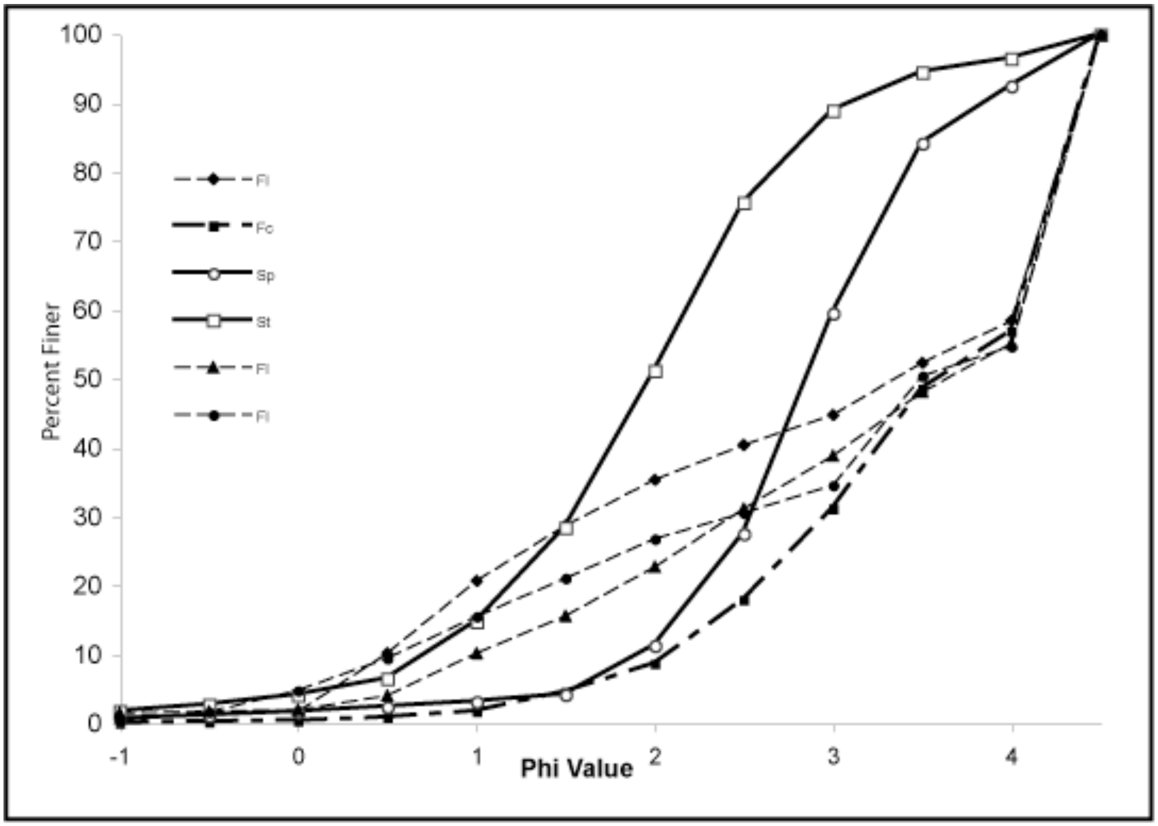

Figure 2.5. Cumulative grain size curves for selected lithofacies. Note lack of sand in fine-grained lithofacies, in particular, the convolute silt (Fc).

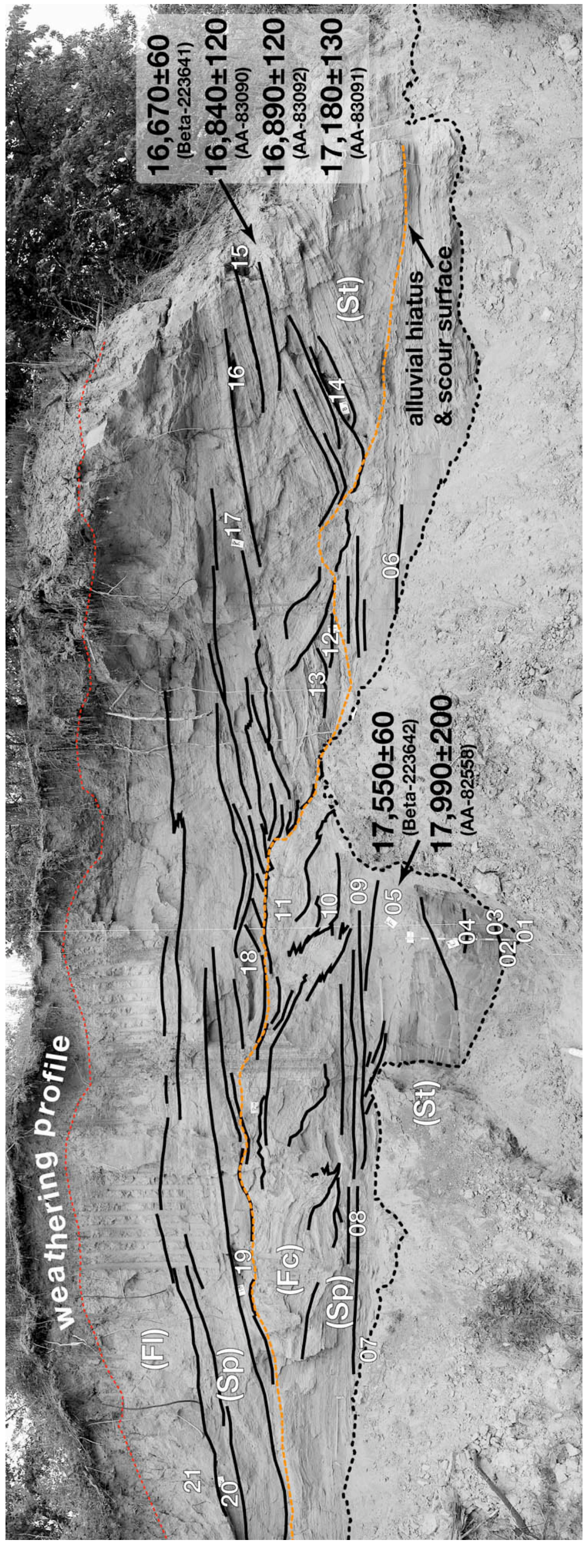

Figure 2.6A. Composite panoramic photograph of the Kulas Quarry exposure. View is to the Northwest. Jacobs staff in lower middle of picture is 1.5 m tall.

Figure 2.6B. Close view of characteristic lithofacies at Kulas Quarry. Color bands on Jacobs Staff are 10 cm wide.

Figure 2.6C. Close up photograph of Fc lithofacies at Kulas Quarry.

Figure 2.7A. Kulas-1 in outcrop. View is to the East.

Figure 2.7B. Closeup view of laminated silt at Kulas-1 showing root traces and deformed bedding (near base). Color bands on Jacobs Staff are 10 cm.

Figure 2.7C. Outcrop exposure of Kulas-2. Farm buildings behind exposure are built on top of the Savanna Terrace surface. View is to the North.

Figure 2.7D. Close up of Fl lithofacies at Kulas-2. Note dark clay-rich band near top of Jacobs staff. Marks on staff are 10 cm tall.

Figure 2.8. Outcrop photo of Hwy-JJ. Total exposure height is approximately 3 m. View is to the West.

Figure 2.9A. Outcrop exposure at JX. Note Jacobs Staff (1.5 m) in center. The top of the exposure is correlative with the Savanna Terrace surface. Note swallow nests within finer Fl and Fm lithofacies near the top of exposure. View is to the East.

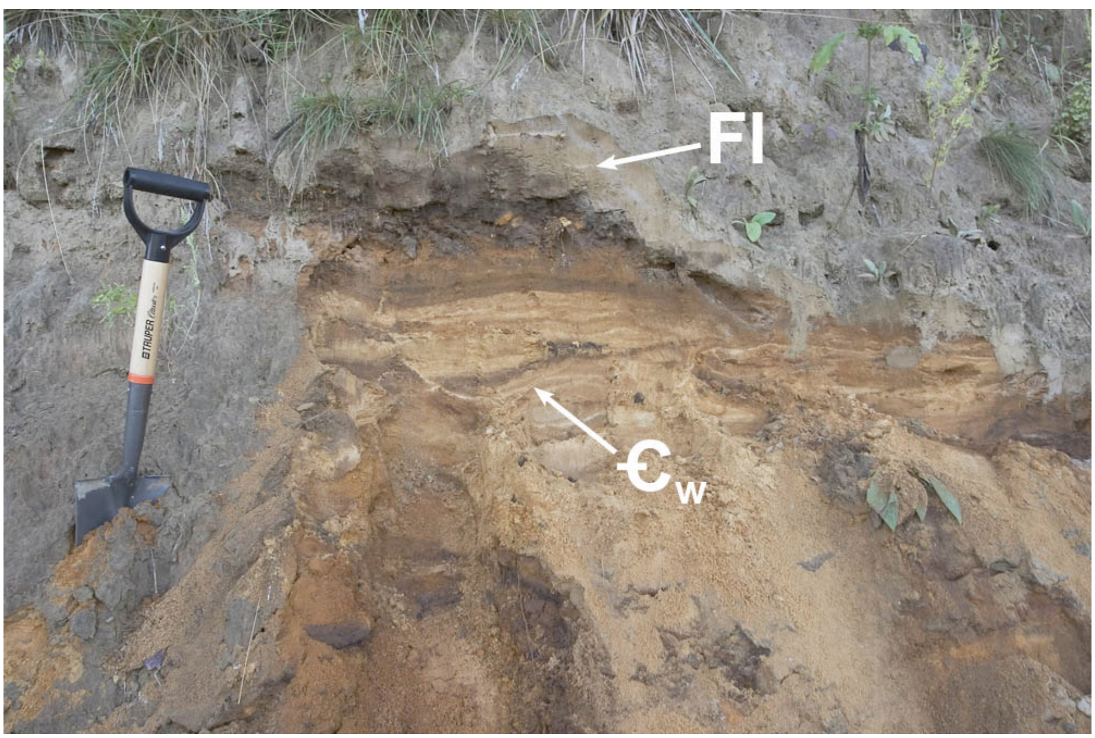

Figure 2.9B. Close view of contact between tan-gray silt and Cambrian Wonewoc Formation. Note irregular, dark weathering surface at contact and incorporated bedrock fragments. Exposure lies approximately 100 m East and 5 m lower than base of JX outcrop. Shovel is approximately 0.8 m tall.

Figure 2.10. Composite panoramic photograph of Storer Creek. Total width of exposure is approximately 200 m. Top of exposure is correlative with Savanna Terrace, and lies approximately 9 m above roadway.

Figure 2.11. Root River exposure. Note Jacobs Staff (1.5 m) in center. This is equivalent to the Lehman site discussed by Mason (1995) and Mason and Knox (1997). The top of the exposure lies approximately 1.5 m below the Savanna Terrace Surface.

Figure 2.12A. Exposure at Hideaway Lane. Jacobs Staff is 1.5 m tall and oriented perpendicular to foreset surface.

Figure 2.12B. Closeup of foreset surfaces at Hideaway Lane. Note the white shell fragments. Circular burrow is modern insect hibernaculum – note box elder bugs at far right.

Figure 2.13. Exposure at Limery Coulee. Jacobs Staff (1.5 m) is to the left of the photograph center. Note bedrock exposure in the back right.

Figure 2.14. Exposure at Big Platte. Fossiliferous material is located along the left side of the exposure. Jacobs Staff (1.5 m) and person (R. Slaughter, kneeling) for scale.

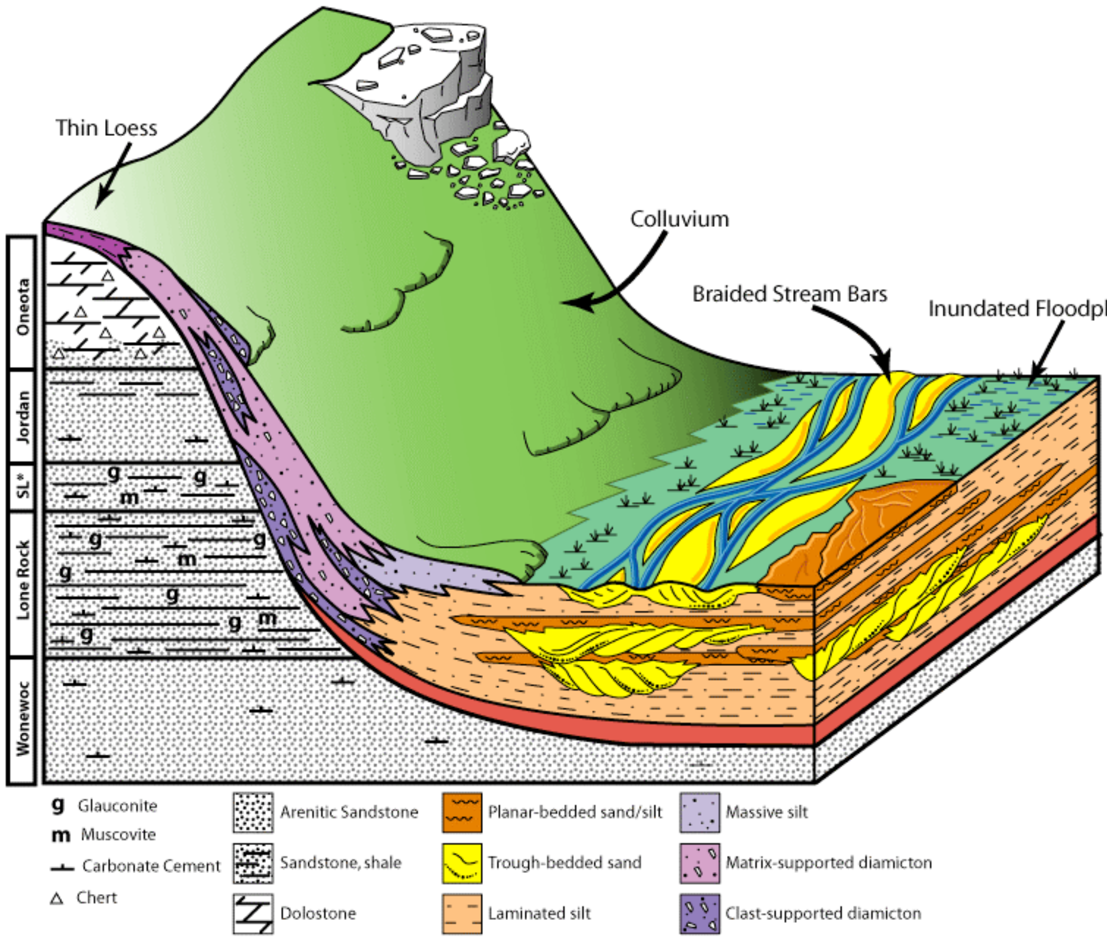

Figure 2.15. Generalized block diagram of a typical UMV cross-section ca. 17,000 cal. yr BP showing spatial relationships and sedimentary architecture with associated lithofacies. Note: backflooding and incision will be inset into these sediments.