Report

Landform Sediment Assemblages in the Upper Mississippi Valley, St. Cloud to St. Paul, for Support of Cultural Resource Investigations

Minnesota Department of Transportation
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This report presents results of geomorphic and landscape sediment assemblage mapping in the upper Mississippi Valley between St. Cloud and St. Paul, Minnesota. The purpose is to provide a context for evaluating the geologic potential for both buried and surficial prehistoric cultural deposits in this reach of the Mississippi Valley. The project was done for the Minnesota Department of Transportation as an enhancement to the Mn/Model project. Mn/Model is a GIS database designed as a planning tool to help avoid pre-Contact archaeological deposits.

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Management Summary

This report presents results of geomorphic and landscape sediment assemblage mapping in the upper Mississippi Valley between St. Cloud and St. Paul Minnesota. The purpose of the report is to provide a context for evaluating the geologic potential for buried and surface prehistoric cultural deposits in this reach of the Mississippi Valley. The project was completed for the Minnesota Department of Transportation and Federal Highway Administration as an enhancement to the Mn/Model project in support of future cultural resource evaluation and mitigation projects.

The geomorphic mapping was conducted directly within the GIS project utilizing ArcMap software; U.S. Geological Survey (USGS) digital raster graphics of 7.5' quadrangle maps; scanned, orthorectified and georeferenced images of USGS NAPP color infrared high altitude aerial photography; scanned, orthorectified and georeferenced images of historic U.S. Department of Agriculture (USDA) black-and-white aerial photography; available USDA digital soil maps for Anoka, Hennepin, Ramsey, Sherburne, and Wright counties; and, 5-foot contour interval topographic mapping flown and created specifically for the project. Delineation of landforms was completed by "heads-up" digitizing, and coding of landforms was conducted using the techniques and code key developed for Mn/Model geomorphology mapping (Hudak and Hajic 1999; Hajic et al. 2000). Seven landscape sediment assemblages (LsSA's) are identified in the project area: undifferentiated uplands, glaciofluvial, catastrophic flood, valley terrace, floodplain, lacustrine, and valley margin. Thirty-two cores were collected to obtain datable material from, and to characterize, different Landform Sediment Assemblages (LfSA's). Twelve radiocarbon samples were selected and assayed at Lawrence Livermore radiocarbon laboratory using the AMS technique. A history of landscape evolution was developed for the project area. LfSA's were then assigned a Landscape Suitability Ranking (LSR) for different depth intervals. The suitability ranking of an LfSA represents a measure of the potential for geological strata to contain and preserve cultural resources with respect to depositional and post-depositional environments and geologic age.

Most of the valley area is occupied by Glaciofluvial and Catastrophic Flood LsSA's that are latest Pleistocene in age, but overlap with earliest Paleoindian presence in North America. The **Lacustrine** LsSA occurs mostly in ice-block depressions on outwash and catastrophic flood surfaces. Lake and wetland deposits filling depressions are latest Pleistocene to modern in age, can be thick, and have a high LSR. Associated shoreline features can also contain buried cultural deposits of all cultural periods. The **Valley Margin** LsSA consists mostly of moderate to steep hillslopes along valley margin, outwash, and catastrophic flood surface margins that are dominated by erosional processes. The **Valley Terrace** LsSA ranges from at least the middle Holocene to late Holocene in age; Middle Archaic to Woodland cultural deposits can be shallowly buried. The **Floodplain** LsSA ranges from late Holocene to modern in age; older occurrences can have shallowly buried Woodland and younger cultural deposits.

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1. Introduction

The Minnesota Department of Transportation (Mn/DOT) requested an assessment of the geomorphology and landform sediment assemblages along the reach of the Mississippi Valley between St. Cloud and the Twin Cities. The assessment is considered an enhancement to the geomorphic contributions of Mn/Model (Hudak and Hajic 1999). This reach of the Mississippi Valley is along a rapidly developing corridor northwest of the Twin Cities. The assessment will benefit planning and environmental assessment, particularly in the evaluation of prehistoric cultural resources. This reach of the Mississippi Valley links the Minnesota Valley and that reach of the Mississippi Valley above St. Cloud, both geomorphically mapped and evaluated as part of the original Mn/Model (Hudak and Hajic 1999). Given this critical position, the St. Cloud to Twin Cities reach will further our understanding of the landscape evolution of the major river valleys in the state, paleoenvironments, and the geologic potential for the burial and preservation of prehistoric cultural deposits.

2. Objectives

The objectives of the investigation are to:

- Build a GIS database for the project area useful for geomorphic mapping;

- Digitize (map) and describe the project area geomorphology and landform sediment assemblages (LfSA's), and assess the age, stratigraphy and depositional environments of the LfSA's; and

- Determine the geologic potential for the location, burial and preservation of intact prehistoric cultural deposits in terms of Landscape Suitability Rankings (LSR's) for LfSA's.

3. Quaternary Geologic Overview

The project reach of the Mississippi Valley extends from just north of St. Cloud, southeastward and southward, to St. Paul, several kilometers downstream of the mouth of the Minnesota River (Figure 1). Within this reach, the Mississippi River flows within a deep trench characterized by multiple terrace and floodplain surfaces. The trench is flanked by a broader late Wisconsin Mississippi Valley composed of a range of high surfaces related to deglacial meltwater discharge. The project location underwent dynamic geologic and geomorphic changes from the latest Pleistocene to the present; many of the changes have implications for finding and interpreting the archaeological record. During the last two millennia of the Pleistocene, when Paleoindian people may have been in the area, these changes include glaciation, deglaciation and ice stagnation; establishment of the broad Mississippi Valley; cutting of the deep Mississippi trench; and responses to major downstream geomorphic changes in the Minnesota and River WarrenValley. Fluvial changes continued throughout the Holocene within the Mississippi Valley trench and tributary valleys. To provide a Quaternary geologic context for the current investigation, the following paragraphs summarize the phases of late Quaternary landscape change for the project area and vicinity, based on conclusions of previous geologic investigations.

- The Superior lobe of glacial ice advanced southwestward (St. Croix Phase) into the Stacy basin (Meyer 1998), which is a southwest–northeast oriented depression on Paleozoic bedrock (Mossler 1983) that extends from northeast Hennepin County to southwest Burnett County in Wisconsin. Ice then advanced to the position of the St. Croix moraine that surrounds the west, south and southeast sides of the basin. In parts of Stearns and Hennepin counties, ice pushed beyond the location of the modern Mississippi River, but in general the ice margin paralleled the east side of the current Mississippi River channel. North of the project area, meltwater flowed southward down the Long Prairie River and west of the western margin of the St. Croix moraine (Wright 1990). Meltwater cut numerous channels in the moraine in Dakota, Hennepin, Ramsey, Washington and Chisago counties, and ultimately drained into the Mississippi (Meyer 1992: Figure 3). Ice retreated and left an ice-cored St. Croix moraine.

- Glacial Lake Lind next formed behind the St. Croix Moraine over the Stacy basin (Johnson 1992). The southwestern part of the lake covers part of Hennepin County west of the present Mississippi River and north of Minneapolis. Reddish brown lake sediment with a Superior basin source was deposited in the lake over the next one thousand years or so. Outlet locations of the lake are uncertain.

- The Superior Lobe readvanced southwestward (Automba Phase, Wright 1972; Wright et al. 1973) to at least the inner margins of the St. Croix Moraine, overriding Glacial Lake Lind sediment (Wright 1972; Clayton 1984; Johnson and Mooers 1998; Meyer 1998), and pushing west of the modern Mississippi River in Hennepin County. Glacial Lake Lind may have continued to exist up the valley of a precursor to the Mississippi (Meyer 1998). Ice then retreated back to the Superior basin.

- A lake re-formed as ice vacated the basin (Johnson 1999; Meyer 1998). The lake may have been a distinct basin, or may have been a continuation of Glacial Lake Lind. Outlet locations are uncertain, as is the timing of lake drainage relative to the advance of the Grantsburg sublobe ice over the basin.

- The Grantsburg sublobe of the Des Moines lobe advanced northeast across the Mississippi Valley project area, overriding the St. Croix Moraine on the west side of the Stacy basin, entering the basin, and stalling at the position of the Pine City Moraine (Hobbs and Goebel 1982). The southeast flank of the Grantsburg sublobe followed the inner margin of the southeast flank of the ice-cored St. Croix Moraine. To the northwest, advancing ice blocked the Long Prairie River course, reversing flow to the north, then east and south to form an early course of the Mississippi River (Schneider 1961; Goldstein 1998). Ice crossed the location of the present Mississippi in the vicinity of easternmost Stearns County. Glacial Lake Grantsburg fronted advancing ice at this position for only about 100 years (Johnson 1994; Johnson and Hemstad 1998). However, when and at what ice position the lake originally formed depends on where the outlet of the preceding glacial lake was located (Meyer 1998). If located in the vicinity of the Mississippi River at the southwest end of the basin, a lake would have formed as ice entered the basin. If located to the northeast, in the vicinity of the current St. Croix River valley, no lake would have formed until advancing ice blocked that valley outlet. Although Grantsburg sublobe meltwater is thought to have coursed through troughs in the St. Croix Moraine, no outlets for Glacial Lake Grantsburg have been identified, possibly because the outlet(s) was over the ice terminus (Cooper 1935) or beneath the ice (Meyer 1998). Ice retreated slightly, possibly opening outlets allowing the lake to drain through the St. Croix Moraine, before stagnating. Ultimately, meltwaters coursing down the Mississippi Valley northwest of the Grantsburg sublobe location are interpreted as having been diverted eastward across Sherburne and Anoka counties, then northeastward across Chisago County, before turning southward along the position of the St. Croix Valley (Meyer 1998: Figure 10). Wright (1972) estimated the age of advance of the Grantsburg sublobe to be about 16,000 B.P. Clayton and Moran (1982) estimated an age of 12,300 B.P. Wood from organic silt underlying Grantsburg sublobe till in Chisago County yielded an age of 11,900 +/- 70 B.P. (Beta-47804) (Meyer 1998). Wood from the base of overlying till yielded an age of 11,850 +/- 60 B.P. (Beta-47059), statistically the same age as the underlying silt. Wood from sand overlying till, also from Chisago County, yielded an age of 12,030 +/- 200 B.P. (W 354) (Wright and Rubin 1956). Again, the age is statistically indistinct from the previous two. Meyer (1998:41) considers the date from the organic silt underlying till to be "somewhat younger than the probable age of the Grantsburg-sublobe maximum." He suggests either the silt was buried by till deposited by a late surge of the sublobe or that the "till" represents mass wasting of stagnant ice debris.

- As the Grantsburg sublobe margin retreated, then wasted, meltwater from the northern part of the lobe escaped eastward, then southward down the location of the St. Croix River Valley (Meyer 1998: Figures 9 and 10). The gap in the moraine in north Minneapolis through which the Mississippi River now flows presumably was not available for meltwater discharge at this time. Extensive sand deposits that form the Anoka Sandplain in the Stacy basin originally were interpreted as outwash sand (Cooper 1935) derived from the retreat and wasting of the Grantsburg sublobe. Currently, these deposits are interpreted as lacustrine in origin (Stone 1965, 1966; Meyer 1985; Meyer and Hobbs 1989; Meyer and others 1990; Patterson 1992; Lehr 1992; Meyer and others 1993; Meyer 1993; Meyer 1998). Meltwaters coursing through the Stacy basin are believed to have been impounded by the Barrens fan (Meyer et al. 1993; Meyer 1998), an hypothesized alluvial fan believed to have emanated from the readvanced Superior Lobe ice, perhaps when ice occupied the position of the Nickerson Moraine (Wright 1972; Clayton 1984), in the position of the modern St. Croix Valley on the northeast side of the basin. Glacial Lake Anoka ensued, with two levels (Hugo and Fridley) recognized below its maximum level (Eginton 1975; Meyer and others 1990; Meyer 1993; 1998). Lake levels presumably were controlled by outlets in eastern Chisago County with drainage (catastrophic at times) down the St. Croix Valley. The morainal gap along the Mississippi River in north Minneapolis presumably had not yet opened. Meyer (1998) cites a radiocarbon age of 11,710 +/- 80 (Beta-37418) on wood from sand below the area covered when the lake was at the Fridley level. The depth of the sample in sand is unclear, as is the relationship, if any, to till deposited by the Grantsburg sublobe. Final drainage of Glacial Lake Anoka occurred when a southern outlet in north Minneapolis opened (Meyer and Hobbs 1989), possibly by melting of stagnant ice occupying a buried valley (Meyer 1998).

- With drainage of Glacial Lake Anoka, the Mississippi developed a broad, high "upper" terrace across part of the Anoka Sandplain (Meyer 1998). In the Red River Valley, Lake Agassiz formed, episodically draining as Glacial River Warren through its southern outlet, episodically cutting and filling the Minnesota River Valley and the Mississippi Valley downstream of the tributary Mississippi River (Upham 1895; Teller and Clayton 1983; Clayton 1983; Matsch 1983; Kehew and Lord 1986; Smith and Fisher 1993; Johnson et al. 1998). Hudak and Hajic (1999) suggest downcutting was not necessarily episodic, but could have occurred during a single catastrophic event. Glacial River Warren may have begun functioning around 11,700 B.P., based on a radiocarbon age associated with the Herman level of Glacial Lake Aggasiz (Teller 1985). When the Minnesota River Valley was tributary to Glacial River Warren, it was lowered to the "middle" terrace level (Meyer and Hobbs 1989; Meyer 1998). Wood and peat collected in 1923 (Cooper and Foot 1932), presumably related to slackwater deposits ponded in the lowest reach of the Mississippi Valley by Glacial River Warren (Meyer 1996), yielded radiocarbon ages of 11,790 +/- 200 (W-454) and 10,200 +/- 300 (W-445), respectively. Lower terraces were also built during later, more restricted flows of Glacial River Warren (Meyer et al. 1990; Meyer 1998). During downcutting of Glacial River Warren, St. Anthony Falls was initiated and migrated 7 miles upstream (Winchell and Upham 1888; Sardeson 1916; Wright 1990; Wright et al. 1998).

4. Methods

Methods follow those outlined for Mn/Model geomorphological investigations (Hajic et al. 2000), modified to take advantage of technical and software advances. Available relevant literature and source data were assembled and assessed for utility toward mapping in the GIS. A GIS database of the project area was built with layers consisting of:

- Digital raster graphics of U.S. Geological Survey (USGS) 7.5’ quadrangle maps;
- Scanned, orthorectified and georeferenced images of USGS NAPP color infrared high altitude aerial photography;
- Scanned, orthorectified and georeferenced images of historic (1951) U.S.Department of Agriculture (USDA) black-and-white aerial photography;
- Available USDA digital soil maps for Anoka, Hennepin, Ramsey, Sherburne and Wright counties; and
- Five-foot contour interval topographic mapping flown specifically for the project.

The 5-foot contour interval mapping allowed mapping at a scale of about 1:12,000 within a 2 kilometer-wide belt centered along the Mississippi River. Flooding delayed data acquisition so that detail was lost in most wooded areas.

Prior to mapping, an initial field reconnaissance was conducted by car to become familiar with the field area.

Heads-up digital mapping was conducted on-screen in ArcGIS 8.1, ArcMap module. The project area includes the entire width of the Mississippi Valley, with the exception of some of the Anoka Sand Plain contact areas. In general, geomorphic mapping and interpretation were conducted with the DRGs and project-specific topography overlying the aerial photography. Digital soil maps were made transparent and toggled on and off as needed for decision-making and mapping. DRGs covering metropolitan areas were altered to reduce the clutter of urban data. The earlier aerial photography revealed detail in tonal contrasts with geomorphic implications that have since been lost with urbanization. Edge-matching with previous digital mapping of the Mississippi River Valley upstream (Hudak and Hajic 1999), and Minnesota River Valley downstream (Hudak and Hajic 1999) was completed after mapping; where possible, the current LfSA polygons were used to complete the edge matching for the most up-to-date coverage and geomorphic interpretations. The geomophology coverage was cleaned and topology built in ArcInfo.

LfSA polygons were tagged with a map label directly in the attribute table that serves as the key field held in common by the project LfSA database and the GIS coverage. The geomorphic mapping was digitally proofed by two different people for map labels, geomorphic location, and geologic continuity. The project LfSA database was constructed in Excel, proofed by three different people, then attached to the GIS coverage to create the GIS coverage attribute table. The Map Unit (LfSA) Field Code Key was updated (Appendix A).

A longitudinal profile was constructed along the length of the project area by projecting terrace elevations to the axis of the valley. For bars and erosional residuals, in most cases only the tops were mapped.

After considerable mapping, a second field reconnaissance of the northern part of the project area was conducted to identify potential coring locations and examine natural exposures (see digital shape file for core locations). Most coring sites were selected based on their potential to yield organic material for radiocarbon dating from key geomorphic features. Access was also a factor. Thirty-two solid near-continuous sediment/soil cores were collected within plastic liners inside a 2-inch diameter Geoprobe soil core. Ends of the plastic liners were sealed and labeled. Cores were located in the northern part of the project area and collected primarily to recover organic material for radiocarbon dating from key geomorphic features. In some locations that were inaccessible to the Geoprobe, a JMC handprobe with 2-inch barrel was used to sample wetlands. Where possible, cores were collected in transects so that profiles could be constructed. Cores were transported to the lab, extracted from the liners, split longitudinally, and described utilizing slightly modified standard soil and sediment techniques and terminology (Soil Survey Staff 1994). The hand probe cores were described and sampled in the field. Core descriptions appear in Appendix B.

Organic matter samples were cut out of cores and sealed in plastic sample bags. Samples were cleaned and identified by Pietra Mueller (Appendix C), and checked by Dr. Eric Grimm, at the Illinois State Museum. Select organic elements were then shipped to the Lawrence Livermore radiocarbon laboratory where they were assayed with the AMS technique.

5. Landscape and Landform Sediment Assemblages

5.1 Upland Landscape

Outliers of uplands (U) are undifferentiated in this project, although they are underlain by drift related to either the Grantsburg sublobe of the Des Moines Lobe, or the Superior Lobe. The outwash plain (Figure 2) surrounds nearly all occurrences. Outlier margins have been smoothed by flowing deglacial meltwaters, either as outwash or large-magnitude flooding.

5.2 Glaciofluvial Landscape

The **Glaciofluvial Landscape** is dominated by a broad outwash plain (OP) that extends almost continuously from the city of St. Cloud southward to the city of Anoka, with possible remnants preserved as far south as the city of Crystal, north of the north Minneapolis gap or constriction in the Mississippi Valley (Figure 2). The outwash plain is the downstream continuation of a narrower outwash terrace that was mapped in the reach of the Mississippi Valley above St. Cloud (Hudak and Hajic 1999). In the northern part of the study reach, the outwash plain is inset up to several meters below, and truncates, older outwash surfaces that carried meltwater from the retreating and wasting Grantsburg sublobe. The plain also is inset below the Anoka Sandplain in the upper part of the study reach. However, farther downvalley, the outwash plain is roughly at the same elevation of the Anoka Sandplain. In this location, the sandplain is usually distinguished from the outwash plain by a greater frequency of ice block depressions, although the boundary is not always distinct.

The outwash plain is characterized by a classic braid pattern surrounding streamlined braid bars (Figure 3). The plain is pitted by numerous ice block depressions that formed as ice blocks once incorporated in or buried by outwash. These depressions range from relative shallow, localized sags in the plain that may support wetlands (OPMA), to deep, steep-sided depressions (OD). Most depressions are clustered in north-northeast – south-southwest trending bands. The banding resulted from melting ice blocks that were trapped in preglacial valleys and subsequently overridden by the ice, or reflect structural differences in the stagnant ice. Most of the depressions are occupied wholly or in part by lakes or marshes that formerly were lakes (see **Lacustrine Landscape**).

Tributaries laden with glacial meltwater from wasting Grantsburg sublobe ice contributed outwash to the Mississippi Valley, and other streams contributed meltwaters from wasting ice. Where the Sauk River crossed the outwash plain, it created at least two outwash surfaces (SKOT1, SKOT2) inset below the Mississippi Valley outwash plain. At the city of Osseo, a smaller tributary deposited a series of outwash fans (OAF1, OAF2, OAF3) atop increasingly younger channeled Mississippi Valley surfaces. Parts of the fan surfaces exhibit distributary channels. The oldest two fans are each truncated by Mississippi River activity. A small sliver of terrace in the mouth of Shingle Creek valley may also represent an outwash fan remnant (OAF). At Anoka, there is a former outwash paleochannel of the Rum River (OPC) inset below a channeled Mississippi Valley surface.

The outwash plain (OP) and related depression (OD) sediment assemblages generally consist of a thin veneer of sandy loam overlying sand and gravel that is in excess of 5 meters thick. Depressions may have a veneer of local slope-derived and eolian material as well. Where depressions support wetlands, peat of variable thickness overlies the sequence. The outwash fans have sandy loam over sand in excess of 2 meters thick.

5.3 Catastrophic Flood Landscape

The **Catastrophic Flood Landscape** consists of a range of surfaces and landforms inset below the **Outwash Landscape**. Catastrophic flood surfaces extend along the length of the project reach. The LfSA's in the **Catastrophic Flood Landscape** are distinguished from **the Outwash Landscape** and interpreted as resulting from large-magnitude flooding because 1) there is a distinct contrast in glaciofluvial style between the fine braid pattern on the outwash plain and the broad paleochannels that followed; and 2) the landform sediment assemblage has many elements considered typical of a **Catastrophic Flood Landscape** (Kehew and Lord 1986), including an inner flood trench, erosional residuals, strath terraces, and boulders in channels. The outwash plain (OP) as mapped may also represent an outer flood-scoured surface with incipient multiple broad channels and a braid pattern superimposed by waning floodwaters. The braid pattern is present in some of the broad paleochannels. Although unresolved, this interpretation is supported by the outer margins of the Mississippi Valley and the outwash plain being carved and defined by some of the broad flood channels in at least the upper half of the project reach. What constitutes a "catastrophic flood" is debatable, and the flood(s) that passed through this reach of the Mississippi Valley certainly were not of the magnitude represented by the Glacial River Warren flood in the Minnesota Valley or Kankakee Torrent in the Illinois Valley (Hajic 1990). However, there is ample evidence of at least one large-magnitude flood coursing down this reach of the Mississippi, particularly when compared to the antecedent conditions. Some previous geologic mapping (Meyer and Patterson 1997) differentiates surfaces that are here included in the **Catastrophic Flood Landscape** from those included in the **Outwash Landscape**. However, there is not a one-to-one correspondence between the current GIS map (see digital maps) and this previous mapping, nor does the previous mapping recognize the possibility of a large-magnitude flood origin for some of the surfaces. Differentiation on the Meyer and Patterson (1997) coverage follows previously introduced terrace names. Meyer and Jirsa (1982) referred to the higher surfaces as the Richfield terrace. Matsch (1962) collectively referred to the lower surfaces as the Langdon terrace.

Although the high and low surfaces have been grouped previously, the longitudinal profile (Figure 4), when combined with the morphology of different terrace remnants, suggests a more complex relationship than a simple stair-step arrangement holding uniformly down the project reach of the valley. Rather, there appears to be a series of nested, or en echelon surfaces consisting of broad paleochannel networks upstream grading to broader, braided surfaces downstream. A series of benches are then inset within the Mississippi trench.

The most distinctive feature of the **Catastrophic Flood Landscape** is a series of broad, anastomosing flood channels (CPC) surrounding flood bars (CB), erosional residuals (CER), and larger terrace (CT) segments. Some of the flood channels have a finer braid pattern superimposed on them (CPCB). Wetlands (CPCMA) occupy segments of these paleochannels that have yet to be drained by younger tributary development. Downstream, the paleochannel networks grade to broader channeled and braided surfaces that, for current mapping purposes, are also identified as paleochannels (CPC, CPCB), although they lack specific large-channel morphology. Downstream of the valley constriction at north Minneapolis, some of the large-magnitude flood surfaces are strath terraces (CST) with thin veneers of sand and gravel. They are cut into Paleozoic bedrock. Inset below the aforementioned surfaces, the Mississippi trench is flanked by a series of narrow benches (CPC) that mark former channel positions as flood waters were focussed and the trench was incised. These lower surfaces adjacent to, and just within, the trench tend to have channel bars (CB) associated with them. Some of these bars that are lower on the landscape may in fact be erosional residuals (CER), but are conservatively mapped as bars.

Downstream of St. Cloud, where the Mississippi Valley widens considerably, there are two main networks of broad catastrophic flood channels (CPC) (Figure 5). One network follows the course of the Mississippi trench, with additional paleochannels west of the trench. Some of these paleochannels merge to the west and south with irregularly walled valleys that formed with the melting of buried ice blocks or that represent former tunnel valley segments. If not filled with ice at the time of large-magnitude discharge, these valleys temporarily would have received flood water. The second network widened to the east, flowed southeast, then southwest, carving the broad arc that distinguishes the Mississippi Valley from the Pierz drumlin field to the north and east. The paleochannels of this second network rapidly coalesce downvalley and rejoin the first network at the city of Elk River. Upon entering the Mississippi Valley, the Elk River flows along the course of the main thread of this paleochannel network until it joins the Mississippi River.

The pattern of anastomosed broad channels incising the outwash plain, then becoming focused toward the Mississippi trench, represented by narrow benches covering a range of elevation, is repeated between Silver Creek township and the city of Elk River. Distinct paleochannels related to this third network are present in, and northwest of, the city of Monticello beyond the Mississippi Trench. Between the cities of Monticello and Elk River, benches with bars along the trench accord with the channels upstream. Downstream from Elk River, parts of the trench become less well defined, perhaps due to the former presence of more easily erodible material. At Elk River, where the modern Mississippi River takes an orthogonal turn to the south, paleochannels widen, and for a short segment, slopes increase (Figure 4). The slopes are actually greater than those illustrated in Figure 4 because the line to which the terraces were pegged is actually longer than the terrace remnants. These relatively steep surfaces likely represent a zone of paleorapids similar in form to those mapped by Hudak and Hajic (1999) for the reach between the cities of Brainerd and St. Cloud. Downstream of the paleorapids, slopes again decrease. Large-magnitude flood surfaces and benches of this network grade to just below, and truncate, the highest Glacial River Warren surfaces (Figure 4; see below).

A forth distinct suite of large-magnitude flood surfaces begins just downstream of Elk River and extends to at least where the Minnesota and Mississippi valleys join. These tend to be intermediate to broad surfaces with a superimposed braid pattern. In Minneapolis, they consist of more narrow benches. At the junction of the Minnesota and Mississippi valleys, this suite of surfaces is higher than, and truncated by, Glacial River Warren surfaces (Figure 4).

The sediment assemblage of catastrophic flood LfSA's consists of sand and gravel, often with a loamy sand to sandy loam veneer (Figure 6, see Core 01ST02; Figure 7). Sand is in excess of 5 meters thick, but locally is thinner south of the north Minneapolis gap. Cobbles and boulders are common on strath surfaces and in the broad paleochannels. Where wetlands are present in flood paleochannels, generally less than 2 meters of peat overlies the sequence (Figures 8, 9 and 10).

Ice block depressions (CD) occur on some of the catastrophic flood surfaces and Mississippi trench walls indicating that ice blocks persisted after formation of the catastrophic flood landscape (Figure 11). In the upper reach of the project, depressions are in line with the depression belts that are well represented on the outwash plain (Figure 2). Other depressions occur just upstream and downstream of the mouth of the Rum River, and a particularly large depression immediately downstream of the north Minneapolis gap, west of the Mississippi River. Lakes formerly occupied these depressions, and are in various phases of infilling (see **Lacustrine Landscape**). Wetlands persist in some of the depressions (CDMA) and former lake beds (LLB, LLBMA). Peat and fine-grained, sometimes organic-enriched, lacustrine sediment in depressions can be in excess of about 8 meters thick (Figures 6, 12 and 13). The wetland and lacustrine sediments overlie sand and gravel.

Where the Mississippi Valley joins the Minnesota Valley, catastrophic flood surfaces related to Glacial River Warren are mapped across the Minnesota Valley mouth. There are at least two relatively high level strath terrace surfaces (MNCST) northwest of the Minnesota trench in the vicinity of the airport. The straths have a variable thin veneer of sand and gravel. The younger surface is present on either side of the Mississippi trench. Both surfaces represent former channels of catastrophic flood discharge that beveled Paleozoic bedrock and earlier glacial deposits in the river junction area. An erosional residual (MNCER) is associated with each of the surfaces (Figure 2). The higher Minnesota Valley strath surface occurs 15.2 to 18.3 meters below a projected elevation of the Mississippi Valley outwash plain, and about 3.0 to 13.7 meters below the highest suite of Mississippi Valley catastrophic flood surfaces (Figure 4). Mississippi Valley catastrophic flood surfaces (that project upvalley to the paleorapids), as well as narrow benches (MNCPC) that were cut during Glacial River Warren inner channel (trench) cutting, truncate the lower Minnesota Valley high strath surface (Figure 4). Downstream of the mouth of the Minnesota River, on the northwest side of the Mississippi (Glacial River Warren) Valley, lies a large catastrophic flood bar (MNCB) similar in scale and morphology to those previously mapped in the Minnesota Valley (Hudak and Hajic 1999). The bar is deposited in a broad arc cut into the valley wall by flood deposits before bar deposition. A variably thin veneer of sand and gravel overlies a bedrock strath near the valley junction, but up the Minnesota Valley, coarse material overlies a drift-filled buried bedrock valley.

St. Anthony Falls, Minnehaha Falls, a suite of relict, unnamed, and possibly previously unrecognized falls, and possibly Coon Rapids, are considered to have been initiated in response to entrenchment of the Minnesota Valley (Wright 1990). These are mapped as part of the **Catastrophic Flood Landscape** (CRP), with the exception of St. Anthony Falls. Historic retreat of St. Anthony Falls has been documented (Sardeson 1916), so the falls are mapped with the Floodplain Landscape below.

5.4 Valley Terrace Landscape

The **Valley Terrace Landscape** is within the Mississippi Trench, inset below the **Catastrophic Flood Landscape**. Upstream of Coon Rapids, valley terraces range about 3.0 to 6.0 meters above the Mississippi River. The **Valley Terrace Landscape** consists of discontinuous remnants of two general terrace levels (VT1, VT2). The two levels are distinguished based on subtle geomorphic differences and different elevations. The VT2 terrace remnants are at the upper end of the elevation range and the VT1 terrace remnants are at the lower end. Associated with each terrace level are related landforms: islands (VI1, VI2), paleochannels (VPC1, VPC2) and for a few of the VT2 terrace remnants, bars (VB2). In some of the major tributary valleys, correlative terraces have been unidentified. They are present, but not differentiated, in other major and intermediate tributaries.

The higher VT2 terrace occurs along all stretches of the project area above the north Minneapolis gap. The largest remnants occur upstream from Elk River. Some of the larger tributaries have terraces that accord with the VT2, at least in their lower reaches. In the Mississippi trench, VT2 remnants are found either immediately downstream of low catastrophic flood surfaces, and are distinguished from the older surfaces by a steep hillslope and a discontinuity in orientation of channel pattern trends, or as isolated remnants backed by the Mississippi trench wall. VT2 remnants are often backed by arcs in the trench wall indicating an increase in sinuosity compared to that exhibited by the catastrophic flood surfaces. In one case, there is an island at the elevation of the VT2 terrace (VI2). It is isolated by a sinuous channel arc cut into the trench wall. Larger VT2 remnants have geomorphic elements that reflect an island braided channel pattern (Figure 14). Ridge and swale topography resulting from lateral migration of stream braids surrounds slightly higher streamlined relict bars or islands (VB2), which also have a superimposed braided pattern. Wetland areas are sometimes present on the terrace remnants at the foot of the backing hillslope (VT2MA). These are fed by groundwater discharging through seeps and springs. Several remnants have distinct paleochannels (VPC2) broader than the typical swales.

The VT2 sediment assemblage consists of loamy sand overlying sand and gravel in excess of 2 meters thick (Figure 15). Cores indicate there is little difference in the assemblage from ridge to swale, or between islands or bars (VB2), and lower lying channel areas. Wetland areas (VT2MA) have less than 2 meters of peat or organic enriched silt over sand and gravel. Mapped paleochannels (VPC2) are filled with at least 2 meters of silty clay loam.

The lower VT1 terrace remnants occur along nearly the entire study reach, but are most common upstream of the city of Anoka. They also occur in major tributary valleys. In the Mississippi trench, VT1 remnants occur in settings similar to the VT2 terrace remnants, as well as downstream and riverward of VT2 remnants. Many VT1 terrace remnants are partially set into the trench walls and exhibit a slightly greater sinuosity than VT2 terrace remnants. Terraces exhibit ridge and swale topography, often in a scroll bar pattern reflecting point bar construction and meander migration (Figure 16). Some of the larger islands (VI1) rise to the level of the VT1 terrace. Larger islands and some VT1 remnants have subtle natural levee rises too narrow to map, even at 1:12,000 scale. On one of the larger diamond-shaped islands, there is a wetland

(VI1MA) apparently confined by such rises. Wetlands (VT1MA) occur on some of the VT1 remnants at the foot of the backing trench wall and/or in swales. There are few cutoff meandering paleochannels (VPC1). They exhibit a lower sinuosity than younger paleochannels.

Some terrace remnants in tributary valleys and valley mouths are undifferentiated (VT). These include some slip-off type slopes. Similarly, there are a few undifferentiated paleochannels (VPC), mostly in tributary valleys

The VT1 sediment assemblage is similar to the VT2 sediment assemblage. Loamy sand overlies sand and gravel in excess of 2 meters thick (Figures 17 and 18). The VT1, VI1, and VT LfSA's have a similar sediment assemblage. Where subtle natural levee rises are present, a thin silt loam cap may be present (Figure 17). Where wetlands are present (VT1MA, VTIMA), less than 2 meters of peat lies atop this sequence (Figure 19). Paleochannels (VPC1, VPC) are filled with silty clay loam in excess of 2 meters thick.

5.5 Floodplain Landscape

The **Floodplain Landscape** is located within the Mississippi Valley trench, and along Mississippi River tributaries. In the project reach, the Mississippi River (FR) exhibits a range of channel morphology. The Mississippi trench consists of straight to gently meandering reaches. Some segments of the modern Mississippi channel inherited the trench morphology, particularly where terraces or floodplains are absent or not well represented (Figure 20). These segments alternate with relatively short meandering segments with a high sinuosity (Figure 21), and relatively short segments that exhibit an island braided pattern (Figure 22). Isolated islands also may occur within straighter segments. The more sinuous segments tend to co-occur where the Mississippi trench intersects belts of ice block depressions, although this association is not entirely consistent. The meandering reaches also tend to exhibit a lower gradient (Figure 4). There appears to be no direct association between the mouths of major tributaries and the different channel patterns. The bed of the modern Mississippi River consists of cobble to pebble gravel and sand and gravel. Deglacial events (see later discussion) resulted in formation and upstream migration of falls in the lowest segment of the study reach (FRP).

Two morphologically distinct, discontinuous, floodplain surfaces and associated landforms are present in the Mississippi trench. The high (FFX) and low (FFW) floodplains are inset about 0.5 to 3 meters below the VT1 surfaces. The high floodplain (FFX) most commonly is present in the stretches where the Mississippi River has the greatest sinuosity. In particular, there are several stretches between St. Cloud and the mouth of the Elk River where the high floodplain is well represented by some of the largest remnants. In these more sinuous stretches, the high floodplain LfSA usually occurs downstream of VT1 remnants. In turn, the low floodplain (FFW) is found downstream of high floodplain and other terraced areas. In high sinuosity reaches, the high floodplain and many low floodplain remnants are characterized by arcuate point bar ridges underlain by point bar sand and overlain by a veneer of finer-textured overbank deposits, combined in excess of 2 meters thick. Generally these are found either in the wake of a major meander migrating downstream, or on the inside of a major meander bend. In straighter reaches, the high and low floodplains occur as narrow floodplain segments and slivers that probably form where the Mississippi River is attempting to establish a meandering regime. Finally, some high and low floodplain areas occur in association with island-braided segments, suggesting they represent lateral bar formation, possibly in advance of a meandering regime. A few of the larger floodplain areas mined for sand and gravel resources have been mapped (FDI).

A number of mostly diamond to lemniscate shaped islands (FI2) accord in elevation with the high floodplain. Lower, generally smaller islands (FI1) accord in elevation with the low floodplain. The islands appear to have been initiated as isolated, or swarms of, channel bars. Some of the larger islands exhibit scroll bars, and many have natural levee ridges too subtle to map. Only rarely are lakes (FLN) present on the islands. A number of the larger, higher islands (FI2) have lower areas (FI2) accreted onto the upstream, downstream, and / or lateral margins (Figure 23). In some cases the accretion is occurring in chutes that are in the early stages of atrophication. In a few instances, former point bars became islands (FI2) as meander channels were abandoned by chute cutoffs. Cutoff meander channels and chutes between islands and the trench wall (FPC2, FPC1) are now in the process of atrophying and infilling. A number of cutoff meanders along the Elk River are also included with the FPC2 LfSA. The cutoff meander of greatest amplitude, located just downstream from Clearwater, has a series of earlier cutoff meanders (Figure 24). A progressive increase in channel width through time from several FPC2 paleochannels to the FPC1 paleochannel suggests a progressive increase in Mississippi River discharge for the time interval represented.

Major and intermittent tributaries have developed their own floodplains and meander belts. The general courses of these streams during the Holocene were determined by antecedent deglacial meltwater conditions. They tend to occupy the locations of former outwash stream valleys, tunnel valleys or catastrophic flood channels. In some cases, such as the Rum River, individual floodplain (FFX, FFW) and island (FI2) LfSA's are identifiable. The Elk River has filled and courses through a number of ice block depressions. Where it enters Elk Lake, an unfilled depression, it has deposited a delta (FDE). Similar deltas, now buried by floodplain and wetland deposits, can be expected in other basins now filled by past fluvial activity. In other cases, such as the Elk River, meander belts (FMB) comprised of undifferentiated floodplain segments and paleochannels are differentiated from terraces. Some areas of meander belts are poorly drained and support wetlands (FMBMA). These areas are probably more extensive than mapped, and seasonally will vary in extent. In a few valleys, such as the Sauk River valley, the terraces and floodplain are undifferentiated (FFN). In the lowest reach of the Clearwater River, Elk River, Elm Creek, and Rice Creek, small reservoirs (FLR) have impounded water through dam construction.

Nearly all of the sediment assemblages of the **Floodplain Landscape** are in excess of 2 meters thick. The FFX sediment assemblage consists of silty clay loam to sandy loam overbank deposits overlying point bar sand (Figure 18). Related FI2 sediment assemblages range from loam to sandy loam over sand and gravel. The FFW and FI1 sediment assemblages tend to have a thicker overbank veneer of silty clay loam, but the veneer can range to fine sand in texture (Figure 25). Paleochannel sediment assemblages (FPC1, FPC2) have an upper increment of silty clay loam fill that accumulated after channel abandonment. This can be greater or less than 2 meters thick, and the finer textured plug overlies channel and lower point bar sand and gravel.

The Elk Lake delta (FDE) is likely to have a fine-textured surficial deposit that may incorporate peat strata and channel sand and gravel. It is possible, and likely, that along tributaries where ice block depressions are present, there are similar deltas in larger depressions that are now buried by alluvium. Tributary meander belt sediment assemblages (FMB) will have a surficial increment that varies from silty clay loam to sandy loam, depending on position relative to former and active channels. Silty clay loam will be thicker in paleochannels. The variable surficial unit overlies sand and gravel channel and point bar deposits. Where wetlands are present (FMBMA), peat or organic-enriched fine texture deposits will top the sediment assemblage. The FFN sediment assemblage will be variable with progressively higher surfaces having a coarser surficial deposit. Only the lower floodplain surfaces are likely to have a silty clay loam overbank veneer.

Small, low order, tributaries have meandering to straight channels. In some cases their courses were influenced by antecedent deglacial events. Where a floodplain is present, it is generally narrow and undifferentiated (FF). Shorter and steeper low order tributaries tend to have "v"-shaped valleys with little or no floodplain (FV). These are more frequently located in the lowest reach of this segment of the Mississippi where trench walls are higher than upstream. It is likely a number of these were initially falls that have since developed a lower, yet still steep, gradient. The FF and FV sediment assemblages are likely to be highly variable, with a variably thick surficial increment of silty clay loam to sandy loam discontinuously overlying sand and gravel (Figure 6).

Deglacial meltwater events created some unique geomorphic situations that are recognized only at more detailed scales of investigation. One such example is a nearly relict fen complex that occurs on a moderately broad high bench (CPC) between the cities of Coon Rapids and Spring Lake Park. A large wetland is perched on the bench. Close examination indicates it was fed by a broad belt of spring-fed channels (FPC) that are now largely inactive (Figure 26). The paleochannels range from straight to meandering, but are undifferentiated except where wetlands still occupy lower lying areas (FPCMA). They were fed by springs emanating from depressions at the margin of the next higher surface, the Anoka Sandplain. The FPC sediment assemblage is probably highly variable, with a very thin, fine-texture veneer over sand and gravel.

5.6 Lacustrine Landscape

The **Lacustrine Landscape** is concentrated in ice block depressions on the outwash plain (OP), and to a lesser degree, on younger catastrophic flood surfaces. Nearly all lakes (LLN) are associated with the belts of ice block depressions. Larger lakes tend to be rounded to ovoid in general shape, reflecting the form of the depressions. Where lakes do not occupy the entire floor of a depression, former lake beds are present (LLB). In many cases, these are occupied by wetlands (LLBMA). Former lake shorelines are represented by beach ridges and sandy strand lines. Some examples of these have been mapped, but most shoreline features are too narrow, or indistinguishable from the foot of basin margin slopes at the scale of mapping. One basin exhibits at least two relict beach ridges (LSH1, LSH2) (Figure 27) indicating past fluctuations in lake margins. Where ice block depression lakes occupy the entire basin floor, shore deposits are likely included within the more general depression (OD, CD) LfSA's.

Lacustrine sediment assemblages can be well in excess of 2 meters thick (Figures 6, 12 and 13). Cores indicate former lake beds (LLB, LLBMA), and at least some depressions, are underlain by variably thick increments of wetland peat overlying peaty to marly fine-texture lake deposits (Figures 6, 12 and 13). Thin beds and laminae of sand are sometimes present in the assemblage. Depending upon where the basin is situated on the landscape and location within the basin, these sands may represent former beach deposits, offshore deposits, localized fluvial, debris flow or fan delta deposits, input from melting ice blocks, or inputs of eolian-derived sand. It is difficult to distinguish the origin without identifying the geometry of the coarser strata by coring at shorter intervals than the objectives of this project allowed.

Beach ridges range in texture from sandy loam to sand and may have locally derived pebble gravel incorporated within them. The beach ridges tend to be narrow, and are likely less than about 2 meters thick.

5.7 Valley Margin Landscape

The **Valley Margin Landscape** primarily consists of steep to moderately sloping hillslopes (MH). Hillslopes are mapped where they are in excess of about 3 meters high. This unit defines the Mississippi trench, as well as scarps formed by progressive channel incision during catastrophic flooding. Colluvial slopes are present at the foot of most hillslopes, but are too narrow to map. Similarly, alluvial fans are scarce and not large enough to map except downstream of the mouth of the Minnesota Valley. In this location, at the foot of the uplands forming the north and northwest valley walls, short, low order tributaries have deposited a bajada of alluvial and colluvial fans (MAF). These fans likely incorporate material derived from glaciofluvial sand and gravel draped on the flanks of the morainal uplands.

Terrace and Mississippi trench scarps (MH) will have little or no veneer of coarse texture hillslope-derived material overlying whatever material the hillslope is developed on. In most cases, this is outwash sand and gravel. The MAF sediment assemblage will vary in thickness, consist of debris flow, sheetflood, and channel deposits, and likely not be well sorted.

6. History of Landscape Evolution

Radiocarbon ages from an outwash plain in the Sauk River Valley (Hudak 1997a) indicate the outwash plain (OP) along the Mississippi Valley below St. Cloud post-dates 11,880 B.P., or about the earliest recognized time of Paleoindian in North America. The Mississippi Valley outwash plain is inset into the higher Sauk Valley outwash surface that carried meltwater from wasting Grantsburg Sublobe ice to the west. The Sauk Valley radiocarbon ages were collected from a wetland in a paleochannel that grades to the higher outwash surface.

The oldest Sauk Valley outwash ages are nearly indistinguishable from the reliable (i.e., not on redeposited pre-late Wisconsin organic material) ages reported in Meyer (1998) from the Stacey basin. Younger non-eolian sands of the Anoka Sandplain are interpreted as having been deposited in Lake Anoka (Meyer 1998, and others). However, the sedimentologic evidence for Lake Anoka has yet to be convincingly developed. Likely as a result, Meyer (1998) rightfully is noncommittal in directly assigning his cited ages to a lacustrine origin, although at least one of the ages (11,710 +/- 80 [Beta-37418]) is discussed in the context of the Fridley level of Lake Anoka. From another perspective, there is little evidence to contradict an outwash interpretation in a setting of much wasting ice with localized lacustrine sedimentation.

Most of the argument for Lake Anoka hinges on an interpretation that the north Minneapolis gap was not yet available for passage of glacialfluvial meltwaters; the presence of a hypothesized outwash fan down the St. Croix Valley that obstructed the eastern side of the Stacey basin; and, interpretation of high channels adjacent to the modern St. Croix Valley as Lake Anoka outlets (Meyer 1998). Limiting radiocarbon ages combined with the longitudinal profile of the Mississippi Valley (Figure 4) suggest the north Minneapolis gap was open by 11,470 B.P., maybe opened by 11,880 B.P., and possibly opened even earlier. It is during this interval that large volumes of sediment were accumulating in the Stacy basin. This material likely represents outwash unable to pass through the gap, if open, and local lacustrine, outwash and debris flow deposits related to wastage of Grantsburg sublobe ice. On the east side of the basin, the configuration of the St. Croix Valley used to interpret an outwash fan and Lake Anoka outlets is younger than anticipated by previous investigators. The valley was carved by catastrophic flooding from Glacial Lake Duluth shortly after 10,000 B.P. (Hudak and Hajic 1999). Sands in Wisconsin interpreted as remnants of the damming outwash fan rather are catastrophic flood LfSA's. The presumed lake outlets can be interpreted as marginal channels carved during earliest stages of this flood.

In addition to the aforementioned evidence and interpretations, there is a lack of geomorphic features that would be expected with a lake the size of Lake Anoka. Lake shorelines cannot be traced, although this may be due to later wasting of stagnant ice. The area where an intact shoreline has been interpreted along with a wave-scoured lake plain, along the eastern side of the basin (Meyer 1998), alternatively can be interpreted as resulting from early St. Croix valley catastrophic flood waters coursing through the basin. The apparent lack of Superior basin sand in young deposits in the Stacey basin would then suggest early flood waters were relatively sediment-free, prior to increased discharge and incision. More obvious in their absence are fan deltas from the Mississippi as well as lesser outwash streams. These should be well-represented in a former lake basin, but none have yet been identified.

Radiocarbon ages on organic material from basal lacustrine deposits filling ice block depressions suggest that the broad paleochannel networks may pre-date about 11,470 B.P. (Table 1). An age of 11,470 ± 70 (CAMS-82502) is from a local sub-basin in a depression on the outwash plain (OP). The depression is open to one of the paleochannels (CPC) that is part of the western paleochannel network at the upstream end of the project area. The next younger age, 11,120 ± 60 (CAMS-82605), is from a depression in a flood paleochannel (CPC) of the same network. The youngest age, 10,100 ± 70 B.P. (CAMS-82506), is from a depression on one of the lower paleochannel remnants cut into the sides of the Mississippi Valley trench and inset below the broad paleochannel network from which the other two depression samples were collected.

Radiocarbon samples from lacustrine deposits in the ice block depressions should post-date formation of the glaciofluvial surface into which they are developed, particularly if there is no overlying sandy facies of glaciofluvial origin or erosional discontinuity in the lacustrine deposits. The oldest age dates material from one of many organic mats interlaminated in an upward-fining basal increment of fine sand to loamy fine sand (Figure 12). It is unlikely such fine material would have been deposited by the adjacent broad paleochannel as it was being cut. Therefore, the northernmost catastrophic flood paleochannel network likely pre-dates 11,470 B.P. The intermediate age comes from a similar facies (Figure 6). The sample yielding the youngest age is from lacustrine deposits. There is a thin increment of gravelly medium and coarse sand of undetermined origin in overlying lacustrine deposits (Figure 13). Nearby in the same basin, coarser strata are more frequently interstratifed with the lacustrine deposits. Sandy strata are underlain by an age of 9,980 ± 50 B.P. (CAMS-82503) (Table 1; Figure 13).

Two radiocarbon samples from the very base of peat in broad paleochannels yielded ages of 10,455 ± 45 (CAMS-82505) and 9,960 ± 45 B.P. (CAMS-82507). The sampled paleochannels are part of the network just downstream of St. Cloud on the northeast side of the valley. The ages indicate this network was abandoned by about 10,460 B.P. at the latest and do not geomorphically or stratigraphically contradict the older aforementioned ages.

Fisher (2001) has dated the major discharge of Glacial River Warren to about 10,700 B.P. This age is in line with several radiocarbon ages around 10,400 B.P. reported from basal alluvial fan deposits in the Minnesota River Valley (Hudak 1997b; Hudak and Hajic 1999). This latter suite of ages also places a minimum age on when the valley floor could have been scoured by large magnitude flooding. That this pre-dates drainage of Lake Agassiz during the Emerson Phase supports the northwest outlet hypothesis (Smith and Fisher 1993; Fisher and Smith 1994) for such late drainage. There are two possible interpretations for the Minnesota Valley strath terraces and erosional residuals that cross the Mississippi Valley at the mouth of the Minnesota River. Either they were cut by the earliest discharge from Glacial Lake Agassiz, about 11,700 B.P. (Teller 1985), or they were cut during the earliest stages of Glacial River Warren catastrophic flooding, in which case they date to slightly older than 10,700 B.P. It is possible that the paleorapids just downstream of Elk River represent a knick zone that was initiated by the initial downcutting of the Minnesota Valley represented by these two high-level surfaces (Figure 4).

In either case, the Mississippi Valley terraces truncated by the Minnesota Valley terraces (Figure 4) indicate that the north Minneapolis gap was open prior to Glacial River Warren, or by 10,700 B.P. at the latest, and possibly was open prior to about 11,470 B.P. If this is indeed the case, then the latest history of the Stacy basin, namely Glacial Lake Anoka and its different levels, needs to be re-evaluated.

The alluvial and colluvial fans located along the lowest part of the project area likely formed in response to the carving of the Glacial River Warren trench, with much of the volume being deposited shortly after trench incision. Similar fan aprons are common up the Minnesota Valley (Hudak and Hajic 1999). Much of the hillslope LfSA dates to this period as well, as the Mississippi trench is incised shortly after the Glacial River Warren trench.

Downcutting that formed the Mississippi trench is not well dated, but much of the downcutting was accomplished by at least 10,100 B.P. If catastrophic or large-magnitude flooding is indeed the main cause of trench formation, then most, if not all, of the downcutting occurred prior to about 9500 B.P. The valley history within the trench for the first few millennia of the Holocene is unclear.

Two radiocarbon samples were collected from a single probe from a wetland on the largest VT2 remnant near the Mississippi trench wall. Wood from alluvium immediately beneath the wetland dated 5,120 ± 50 B.P. (CAMS-82501). Bark from the base of overlying organic silt deposits dated 5,000 ± 40 B.P. (CAMS-82499) (Table 1). The ages indicate the VT2 remnant was abandoned shortly after 5000 B.P. and that the VT1 terrace post-dates this age. This also approximates the transition from an island braided Mississippi River to a meandering one, at least in this stretch of the valley. Initiation of the VT2 LfSA is unknown. There may be a morphological continuum between surfaces mapped as low catastrophic flood surfaces and the VT2 LfSA. The size of flood bars and braided islands is comparable. However, no ages on the transition are currently available.

On a VT1 remnant just downstream and on the opposite side of the river of the dated VT2 remnant, probes from one of the oldest and one of the youngest swales yielded datable material. The older sampled site is a small fen fed by spring water just beyond the foot of the trench wall. Charcoal from the base of fen deposits overlying alluvium yielded an age of 2,910 ± 50 B.P. (CAMS-82498). The younger sampled site is a wetland perched in one of the younger swales. *Pineaceae sp.* cone fragments from near the base of wetland deposits overlying alluvium yielded an age of 1,280 ± 35 B.P. (CAMS-82500) (Table 1). An age of 2,030 ± 45 B.P. (CAMS-82497) from a cutbank opposite Clearwater was obtained on charcoal that was collected from just underneath low natural levee deposits on a VT1 remnant. Ages from the VT1 LfSA indicate it is late Holocene in age, and mostly pre-dates about 1,300 B.P.

The Floodplain Landscape represents a continuation of the meandering regime into modern times, at least along certain stream segments, but at slightly lower elevations. The age of this landscape is undated, but it was initiated during the very late Holocene. At least the upper increments of the FFW LfSA and related LfSA's are considered historic to modern in age.

7. Landscape Suitability Rankings for Surface and Buried Archaeological Sites

In Mn/Model, the geologic potential for surface and buried prehistoric cultural deposits is discussed in terms of landscape suitability rankings (LSR's) (Hudak and Hajic 1999). The LSR index is objectified to the extent possible by considering the age of the deposits (old enough, too old, too young) and the degree to which depositional environments, based on depositional energy, are likely to contain and preserve intact cultural deposits.

Most of the **Outwash Landscape** is unlikely to contain and preserve intact buried cultural deposits, although it is a possibility. Radiocarbon ages from the study reach of the Mississippi Valley and regional context suggest the **Outwash Landscape** was actively forming when the earliest Paleoindian people are documented to have been on the continent. The surface of the outwash plain could support Early Paleoindian and younger deposits, although it is unlikely they would be intact, given the range of post-depositional processes acting over the last 10,000 years or so. Depositional environments of the outwash plain LfSA would not have been conducive to preservation of buried intact cultural deposits because of the dynamic nature and energy of the braided stream environment, particularly in channeled areas. However, there is a low possibility intact cultural material may be on, or very shallowly buried in, fine sandy bar-top deposits. In the outwash fans, Early Paleoindian cultural deposits, if present, could have been buried in relatively lower energy distal fan deposits as the fans prograded. Proximal fans are characterized by a range of processes, most of which reflect high energy environments. Because of the variability, however, a low possibility for intact buried cultural deposits must be considered.

Ice block depressions indicate some of the outwash landscape did not completely stabilize for some time as buried ice blocks melted. In these cases, younger deposits derived from depression slopes and eolian influx could have shallowly buried cultural deposits younger than Paleoindian. Thus, the suitability is ranked moderate for the upper meter. In basins where wetlands are present, peat accumulation is an additional process that is conducive to burial and preservation of intact cultural deposits. For such depressions, the suitability is ranked high in the upper meter containing the peat, and low for the meter beneath that contains ice-block melt slump deposits.

The **Catastrophic Flood Landscape** was actively forming during the Paleoindian period. Environments of deposition generally were not conducive to burial of intact cultural resources and rankings are nil for most LfSA's at the greater-than 1 meter depth. Again, there is a remotely low possibility of very shallow burial in the surficial increment of sandy loam to fine sand on many of the surfaces, including braid bars that may have resulted from waning flood currents. Similar to the **Outwash Landscape**, ice block depressions with and without wetlands are present on catastrophic flood surfaces and in the broad paleochannels. As with the other ice block depressions, suitability is ranked moderate or high for the upper meter, depending on whether peat is present. Some of the depressions have thicker peat so the high ranking is carried into the 1- to-2-meter depth interval. Also, some of the depressions have lacustrine fill, so a moderate ranking for the greater than 2-meter depth interval is assigned.

The interval over which the VT2 LfSA formed is unknown, although it appears to have been abandoned as a terrace sometime during the middle Holocene. The likelihood of buried cultural deposits is ranked low for all but the uppermost increments of the deposit, but considered almost nil. If present and intact, buried cultural deposits will be Middle Archaic and older in age. Cultural deposits likely no older than Middle Archaic will be found on the VT2 terrace. If present, they are more likely to be on ridges or island/bars, although differences in drainage conditions compared to at least some of the swales is negligible.

The VT1 landscape is late Holocene in age and represents a meandering stream depositional environment. Middle Archaic and younger cultural deposits, if present, may be buried intact in upper point bar (moderate likelihood) and overbank deposits (high likelihood), but would not be expected at depth. If present, cultural deposits no older than late Middle Archaic would also be found on the VT1 terrace. If present, they are more likely to be on the better drained scroll bar ridges. For swales that support wetlands, the upper meter is ranked high reflecting the low energy depositional environment. However, the surface is ranked nil because it is modern in age.

The FFX LfSA and related LfSA's are very late Holocene in age. The landscape suitability for these LfSA's in the Mississippi and larger tributaries generally is ranked moderate to a depth of 2 meters, reflecting the upper point bar and overbank depositional environments. If present, Late Woodland and younger cultural deposits are possible in buried and surface contexts. However, some remnants may also have a thin veneer of historic overbank deposits. The FFW LfSA and related LfSA's are historic to modern in age, but may have deposits of very late prehistoric age at depth. The historic age yields a nil landscape suitability ranking for near-surface deposits. These deposits will be thicker in the paleochannels. A moderate ranking is assigned to the 1- to-2-meter interval to cover the possibility that not all of the LfSA(s) is historic in age.

Landscape suitability rankings for the **Floodplain Landscape** in intermediate and small tributaries is highly variable, depending on the resolution of mapping, stream location and order, and gradient. In general, low order, steep gradient streams are mapped as the FV LfSA. These are generally characterized by intermittent to perennial streams with coarse bedload and little or no floodplain. They are ranked low, but if not for the slight possibility of preservation of small floodplain or terrace remnants, they would be ranked nil. Low to intermediate order streams of moderate gradient generally are mapped as the undifferentiated FF LfSA. They are ranked moderate only to cover the great variability likely to be present.

In the **Lacustrine Landscape**, lake basin deposits are latest Wisconsinan through the Holocene in age. Where wetlands are present, and in existing lakes, surficial deposits can be expected to be historic in age. The LSR for prehistoric lacustrine and wetland deposits is high, reflecting the low depositional energy of the lacustrine environment.

Available radiocarbon evidence from lacustrine deposits suggests beach ridges are Holocene in age, although none have been dated directly. Radiocarbon ages and the distribution of archaeological sites around Mille Lacs Lake, a much larger lake to the north of the project area, suggest Woodland and younger cultural deposits, if present, will be found on beach ridges, whereas Woodland and older sites, if present, can be expected in buried contexts within beach ridges (Trocki and Hajic, 2000). Beach ridges buried by younger lacustrine or wetland deposits would be expected to pre-date the latest Holocene.

The **Valley Margin Landscape** has variable LSRs reflecting the two different landform sediment assemblages. Moderate to steep hillslopes along the valley and other surface margins are latest Wisconsinan to late Holocene in age, although they are formed mostly in older drift. However, they are assigned a low ranking because of hillslope processes likely to affect the integrity of any prehistoric cultural deposits. Soil creep, heave, sheetflood erosion and sedimentation, rill erosion, and mass wasting would limit the integrity of any cultural deposit associated with this LfSA. Deposits on the shoulder slopes and sideslopes are likely less than a meter thick.

The alluvial and colluvial fan LfSA is latest Pleistocene in age, and may bury and/or contain Paleoindian cultural deposits. Surface cultural deposits, if present, could be Paleoindian and younger in age. The fans are assigned a moderate LSR ranking.

After completion of the LfSA mapping and interpretation, the State Historic Preservation Office (SHPO) site database was checked for sites recorded to date within the mapped area as a check on the landform sediment assemblage model. The database has 44 recorded prehistoric sites within the mapped area. Twelve sites occur on outwash surfaces, 21 on catastrophic flood surfaces (including three on Glacial River Warren surfaces on the southwest side of the Mississippi Valley), two on valley terrace surfaces, two on valley margin hillslopes (in close proximity to the three on Glacial River Warren surfaces), three on floodplain surfaces, and four on lacustrine surfaces.

Of the 44 sites, 15 sites have no diagnostic artifacts that would allow temporal affiliation. Of the remaining 29 sites, 2 are assigned to Paleoindian, 5 to Archaic, 25 to Woodland, and 2 to the contact period. Four sites are multicomponent with two or more assigned ages.

Of the 29 sites with some type of temporal affiliation, only one has an apparent discordant relationship between cultural affiliation and landform age estimated through geologic and radiocarbon assessment. An undifferentiated valley terrace remnant (VT) has a site that is assigned to the Paleoindian period based on a single Clovis projectile point. The earliest age of the older valley terrace is uncertain, but it certainly post-dates Early Paleoindian. The remnant in question is just downstream of St. Anthony Falls, which is why the surface was undifferentiated within the valley terrace landscape. There are several possible explanations for the apparent age discrepency. On the geologic side, the surface could be incorrectly assigned to the wrong landscape. It is a relatively high remnant in relation to other VT2 surfaces and could actually be one of the narrow erosional benches of the catastrophic flood landscape (CPC). The remnant was undifferentiated because of the possibility that St. Anthony Falls has retreated during the Holocene (Sardeson, 1916; Wright, 1990), and the surface could conceivably be much younger than surfaces of comparable height above the river upstream of St. Anthony Falls. Perhaps, however, the remnant in question is part of the catastrophic flood landscape. It is possible that the retreat of St. Anthony Falls was initially quite rapid in response to downcutting in the Minnesota Valley. Perhaps St. Anthony Falls has not retreated significantly during the Holocene. Alternatively, on the archaeological side, the site apparently is defined by a single projectile point. As with all site temporal affiliations unconfirmed by multiple diagnostic artifacts, it is possible that the point was found, used and discarded by a younger prehistoric cultural group.

The only other possibly questionable situation occurs in association with an exposed lake bed in a relatively large depression on the broad catastrophic flood surfaces north of the north Minneapolis gap on the west side of the river. Three closely spaced sites with Woodland affiliations occur on what is mapped as an exposed lake bed. One of the sites occurs in a wetland (LLBMA) in the basin within 0.10 km from the edge of the basin. The other two sites occur within meters of the wetland on the exposed lake bed (LLB). The model of landscape evolution interprets an essentially modern land surface age for wetlands in these larger former lake basins where peat is actively being deposited. It is possible that the surface of the peat is not modern or historic across the basin. There may be minor beach or shoreline ridges too narrow to be recognized or mapped that provide slightly better local drainage conditions within the former lake basin. Another explanation may be that these sites were recognized beneath the current land surface by subsurface sampling techniques.

8. Conclusions

The broad upper Mississippi Valley between St. Cloud and St. Paul is dominated by braided outwash and large-magnitude flood surfaces. A wide trench in which the Mississippi River flows is flanked by additional large-magnitude flood surfaces and narrow benches. These surfaces formed in response to deglacial outwash events and incision of Glacial River Warren down the Minnesota Valley. The outwash and flood surfaces are latest Wisconsinan in age, but overlap in time with the earliest documented Paleoindian presence in North America. The locations and courses of most tributary valleys were influenced by these latest deglacial events.

Outwash and large-magnitude flood surfaces, including some within the Mississippi trench, are modified by ice block depressions. Radiocarbon ages suggest stagnant ice blocks may have lasted nearly into the Holocene. Many of the depressions functioned as lake basins as they filled over the Holocene. A number of lakes are yet unfilled. Locally there is beach ridge evidence of past shorelines and lake level fluctuation.

Within the Mississippi trench there are two low discontinuous terraces that are middle to late Holocene in age, and two discontinuous floodplain levels. Relict features associated with these terraces record a Mississippi River transition from island braided to meandering river during the Middle Holocene. Later floodplain features also record a meandering stream, with hints of fluctuating discharge. However, there are reaches of the modern Mississippi that also reflect straight and island braided channel patterns. The various channel patterns suggest that this reach of the Mississippi River has yet to reach a state of dynamic equilibrium.

There is only the slightest possibility of Paleoindian material being very shallowly buried intact in association with bar-top deposits in the outwash or catastrophic flood landform sediment assemblages. Shallow burial of Paleoindian and younger (possibly as young as Woodland) cultural deposits is possible around depression basins, particularly in association with low beach ridges and colluvial deposits. Within the Mississippi Trench, shallow burial of intact Middle Archaic and older cultural deposits is possible in the VT2 LfSA. Middle Archaic and younger cultural deposits could be buried in the VT1 LfSA in association with upper point bar and overbank deposits. Late Woodland and younger cultural deposits are possible in the older floodplain surfaces. The younger floodplain surfaces are still forming today, but may have been initiated during prehistoric time.

9. References Cited

Clayton, L.

1983 Chronology of Lake Agassiz Drainage to Lake Superior. In *Glacial Lake Agassiz; Geological Asssociation of Canada Special Paper 26*, pp. 291-307. University of Toronto Press.

1984 Pleistocene Geology of the Superior Region, Wisconsin. In *Wisconsin Geological and Natural History Survey Information Circular*, vol. 46, p. 40.

Clayton, L., and S. R. Moran

1982 Chronology of the Late Wisconsinan Glaciation in Middle North America. In *Quaternary Science Reviews,* vol. 1, pp. 55-82. Pergamon Press Ltd., Great Britain.

Cooper, W. S.

1935 The History of the Upper Mississippi River in Late Wisconsin and Postglacial Time. In *Minnesota Geological Survey Bulletin* 26, p. 115. The University of Minnesota Press, Minneapolis.

Cooper, W. S., and Foot, H.

1932 Reconstruction of a Late-Peistocene Biotic Community in Minneapolis, Minnesota. *Ecology*vol. 13, pp. 63 -72.

Eginton, C. W.

1971 Geology of the White Bear Lake West Quadrangle, Minnesota. *M.S. Thesis – Oklahoma State University*, p. 56. Oklahoma State University, Stillwater, Oklahoma.

Fisher, T. G.

2001 Final Abandonment of Lake Agassiz's South Outlet at 10.7 KA BP. In *Geological Society of America, Abstracts with Programs,* vol. 32, No. 7, p. 331.

Fisher, T. G. and D. G. Smith

1994 Glacial Lake Agassiz: Its Northwestern Maximum Extent and Outlet in Saskatchewan (Emerson Phase). *Quaternary Science Reviews*, vol. 13, pp. 845-858.

Goldstein, B. S.

1998 Quaternary Stratigraphy and History of the Wadena Drumlin Region, Central Minnesota. In *Contributions to Quaternary Studies in Minnesota. Minnesota Geological Survey Report of Investigations*, edited by C. J. Patterson and H. E. Wright, Jr., 49, pp. 61-84, St. Paul.

Hajic, E. R.
1990 Late Pleistocene and Holocene Landscape Evolution, Depositional Subsystems, and Stratigraphy in the Lower Illinois River Valley and Adjacent Central Mississippi River Valley. Unpublished Ph.D. dissertation, University of Illinois at Urbana-Champaign, 301 p.

Hajic, E. R., P.E. Paradies, and C.M. Hudak
2000 Manual for How to Construct a Mn/Model Landscape Suitability Model. Report prepared by Foth & Van Dyke for the Minnesota Department of Transportation. 34 pp. plus appendices.

Hobbs, H. C. and J. E. Goebel
1982 Geological Map of Minnesota. In *Quaternary Geology,* Map S-1, University of Minnesota.

Hudak, C. M.
1997a Geomorphology of the Proposed T.H. 23 Alternate Corridors (S.P. 7305-83), Report prepared by Foth & Van Dyke for the Minnesota Department of Transportation. p. 9.

1997b Phase I Geomorphological Investigation of the T.H. 169 Corridor Between North Mankato and St. Peter, Minnesota (S.P. 5211-45). Report prepared by Foth & Van Dyke for the Minnesota Department of Transportation.

Hudak, C. M., and E. R. Hajic
1999 Landscape Suitability Models for Geologically Buried Precontact Cultural Resources. In *A High Probability Predictive Model of Precontact Archaeological Site Location for the State of Minnesota.* Minnesota Department of Transportation CD-ROM Report and GIS ArcView Coverages.

Johnson, M. D.
1992 Glacial Lake Lind: A Long-lived Precursor to Glacial Lake Grantsburg in Western Wisconsin and Eastern Minnesota [abs.]. *Geology Society of America abstracts with Programs*, vol. 24, p. 24.

1994 Evidence for a Short-lived Glacial Lake Grantsburg [abs.]. *Geological Society of America Abstracts with Programs,* vol. 26, p. 22.

1999 Pleistocene Geology of Polk County. *Wisconsin Geological and Natural History Survey Bulletin* 92.

Johnson, M. D., D. M. Davis and J. L. Pederson
1998 Terraces of the Minnesota River Valley and the Character of Glacial River Warren Downcutting. In *Contributions to Quaternary Studies in Minnesota. Minnesota Geological Survey Report of Investigations* edited by C. J. Patterson and H.E. Wright, Jr., 49, pp. 121-130. St. Paul.

Johnson, M. D. and C. Hemstad

1998 Glacial Lake Grantsburg: A Short-lived Lake Recording the Advance and Retreat of the Grantsburg Sublobe. In *Contributions to Quaternary Studies in Minnesota. Minnesota Geological Survey Report of Investigations* , edited by C. J. Patterson and H.E. Wright, Jr., 49, pp. 49-60. St. Paul.

Johnson, M. D. and H. D. Mooers

1998 Ice-margin Positions of the Superior Lobe During Late Wisconsinan Deglaciation. In *Contributions to Quaternary Studies in Minnesota. Minnesota Geological Survey Report of Investigations*, edited by C. J. Patterson and H. E. Wright, Jr., 49, pp. 7-14. St. Paul.

Kehew, A. E. and M. L. Lord

1986 Origin and Large-scale Erosion Features of Glacial Lake Spillways in the Northern Great Plains. In *Geological Society of America Bulletin,* vol. 97, pp. 162-177.

Lehr, J. D.

1992 Aggregate Resources and Quaternary Geology Isanti County, Minnesota. Plate I, Report 304, Minnesota Department of Natural Resources, Division of Minerals, 1 sheet.

Matsch, C. L.

1962 Pleistocene Geology of the St. Paul Park and Prescott Quadrangles. *M.S. Thesis – University of Minnesota*, p. 49.

1983 River Warren, the Southern Outlet of Glacial Lake Agassiz. In *Glacial Lake Agassiz; Geological Association of Canada Special Paper* 26, edited by J. T. Teller and L. Clayton, pp. 231-244. University of Toronto Press.

Meyer, G. N.

1985 Quaternary Geologic Map of the Minneapolis-St. Paul Urban Area, Minnesota. Minnesota Geological Survey Miscellaneous Map Series M-54, scale 1:48,000.

1992 Quaternary Stratigraphy (part of Plate 5). In Geologic Atlas of Ramsey County, Minnesota, edited by G. N. Meyer and L. Swanson. Minnesota Geological Survey County Atlas Series C-7.

1993 Quaternary Geologic Map of Chisago County, Minnesota. Minnesota Geological Survey Miscellaneous Map Series M-78, scale 1:100,000.

1996 Geology of the Bassett Valley Area. *Minnesota Geological Survey Open-File Report*, 96 3, 6 p.

1998 Glacial Lakes of the Stacy Basin, East-central Minnesota and Northwest Wisconsin. In Contributions to Quaternary Studies in Minnesota. In *Minnesota Geological Survey Report of Investigations*, edited by C. J. Patterson and H. E. Wright, Jr., 49, pp. 35-48. St. Paul.

Meyer, G. N., R. W. Baker and C. J. Patterson
1990 Surficial Geology. Plate 3 in *Geologic Atlas of Washington County, Minnesota. Minnesota Geological Survey County Atlas Series C-5*, edited by L. Swanson and G. N. Meyer, scale 1:100,000.

Meyer, G. N. and H. C. Hobbs
1989 Surficial Geology. Plate 3 in *Geologic Atlas of Hennepin County, Minnesota. Minnesota Geological Survey County Atlas Series C-4*, edited by N. H. Balaban, scale 1:100,000.

Meyer, G. N. and M. A. Jirsa
1982 Aggregate Resource Inventory of the Seven County Metropolitan Area, Minnesota. Unpublished report prepared by the Minneosta Geologial Survey for the Twin City Metropolitan Council, cited in G. N. Meyer and C. J. Patterson, 1997.

Meyer, G. N. and C. J. Patterson (Compilers)
1997 Surficial Geology of the Anoka 30 x 60 Minute Quadrangle, Minnesota. Minnesota Geological Survey Miscellaneous Map Series M-77, scale 1:100,000.

Meyer, G. N., C. J. Patterson, H. C. Hobbs and J. D. Lehr
1993 Surficial Geology. Plate 1 in *Regional Hydrogeologic Assessment, Anoka Sand Plain - Anoka, Chisago, Isanti and Sherburne Counties, Minnesota*, edited by G. N. Meyer and J. Falteisek, Minnesota Department of Natural Resources, Division of Waters Regional Assessment Series RHA-1, scale 1:200,000.

Mossler, J. H.
1983 Bedrock topogrpahy and Isopachs of Cretaceous and Quaternary Strata, East-central and Southeastern Minnesota. In *Minnesota Geological Survey Miscellaneous Map Series M-52*, scale 1:500,000, St. Paul.

Patterson, C. J.
1992 Surficial Geology. Plate 3 in *Geologic Atlas of Ramsey County, Minnesota*, edited by G. N. Meyer and L. Swanson, Minnesota Geological Survey County Atlas Series C-7, scale 1:48,000.

Sardeson, F. W.
1916 Minneapolis-St. Paul Folio, Minnesota. *Geologic Atlas of the United States, U.S. Geological Survey Geologic Folio 201*, 14 p.

Schneider, A. F.
1961 Pleistocene Geology of Randall Region, Central Minnesota. Bulletin 40, p. 151. University of Minnesota Press.

Smith, D. G. and T. G. Fisher
1993 Glacial Lake Agassiz – the Northwestern Outlet and Paleoflood. Geology, vol. 21: 9-12.

Soil Survey Staff
1994 Keys to Soil Taxonomy, 6th Edition, SCS, USDA, Washington, D.C., p. 524.

Stone, J. E.
1965 Reconnaissance Map of the Surficial Geology of the Minneapolis-St. Paul Area. Minnesota Geological Survey File Map, scale 1:250,000.

1966 Surficial Geology of the New Brighton Quadrangle, Minnesota. *Minnesota Geological Survey Geologic Map Series GM-2*, 39 p., scale 1:24,000.

Teller, J. T.
1985 Glacial Lake Agassiz and its Influence on the Great Lakes. In *Geol. Association of Canada Special Paper 30*, edited by P.F. Karrow and P.E. Calkin, p. 16. Geological Association of Canada.

Teller, J.T. and L. Clayton
1983 Glacial Lake Agassiz; Geological Association of Canada Special Paper 26, edited by J. T. Teller and L. Clayton, pp. 263-290. University of Toronto Press.

Trocki, P.A., and E.R. Hajic
2000 Phase I Archaeological and Geomorphic Investigations Along T.H. 169 Between T.H. 27 and Garrison Mille Lacs, Crow Wing, and Airkin Counties, Minnesota (S.P. 1804-48 and S.P. 1804-50). Report prepared by Foth & Van Dyke for the Minnesota Department of Transportation, 169 pp. plus appendices and drawings.

Upham, W.
1895 The Glacial Lake Agassiz. *USGS Monographs,* vol. 25, p. 658. Government Printing Office, Washington, D.C.

Winchell, N. H. and W. Upham
1888 The Geology of Minnesota, Volume II. Minnesota Geological and Natural History Survey, 695 p.

Wright, H.E., Jr.
1972 Quaternary History of Minnesota. In *Geology of Minnesota: a Centennial Volume,* edited by P.K. Sims and G.B. Morey, pp. 515-547. Minnesota Geological Survey, St. Paul.

1990 Geologic History of Minnesota Rivers. In *Minnesota Geological Survey, Educational Series 7,* 20 p. University of Minnesota, St. Paul, Minnesota.

Wright, H.E., Jr., K. Lease, and S. Johnson
1998 Glacial River Warren, Lake Pepin and the Environmental History of Southeastern Minnesota. In *Contributions to Quaternary Studies in Minnesota*., edited by , C. J. Patterson and H. E. Wright, Jr., Minnesota Geological Survey Report of Investigations 49, pp. 131-140. St. Paul.

Wright, H. E., Jr. C. L. Matsch, and E. J. Cushing
1973 Superior and Des Moines Lobes. In *The Wisconsinan Stage, Geological Society of America Memoir* 136, edited by R. F. Black, R.P. Goldthwaite and H.P. Willman, pp. 153-185. Geological Society of America.

Wright, H. E., Jr. and M. Rubin
1956 Radiocarbon Dates of Mankato Drift in Minnesota. *Science*, vol. 124, pp. 625-626.

Table 1

Radiocarbon Ages from
Depression, Catastrophic Flood, and Valley Terrace Landform Sediment Assemblages

RCYBP	Sample Number	LfSA	Sample Material	Lab Number
1,280 ± 35	01ST11; 1.90-2.00	wetland in youngest swale of ridge and swale topography (VT1MA) overlying VT1 terrace	uncarbonized Pinaceae cone fragments	CAMS-82500
2,030 ± 45	01SH10 cutbank	low terrace (VT1) beneath low natural levee	single large unidentified charcoal fragment	CAMS-82497
2,910 ± 50	O1ST12; 1.45-1.60	wetland (fen) in oldest swale of ridge and swale topography (VT1MA) overlying VT1 terrace	unidentifiable fine charcoal fragments	CAMS-82498
5,000 ± 40	01SH18; 1.17-1.20	wetland in older swale of ridge and swale topography (VT2MA) overlying VT2 terrace	uncarbonized, unidentified bark	CAMS-82499
5,120 ± 50	01SH18; 1.25	older swale of ridge and swale topography (VT2MA) on VT2 terrace	uncarbonized, unidentified wood	CAMS-82501
5,360 ± 140	01SH16; 4.96-4.98	wetland in relict lakebed (LLBMA) in ice block depression in catastrophic flood paleochannel (CPCB)	unidentified fine charcoal fragments	CAMS-82504
9,960 ± 45	01ST05; 3.44-3.46	wetland (CPCMA) in broad catastrophic flood paleochannel (CPC)	uncarbonized Spruce or Larix wood	CAMS-82507
9,980 ± 50	01SH16; 8.18-8.23	wetland in relict lakebed (LLBMA) in ice block depression in catastrophic flood paleochannel (CPCB)	uncarbonized Spurce and Larix needles	CAMS-82503
10,100 ± 70	01SH15; 3.55-3.57	wetland in relict lakebed (LLBMA) in ice block depression in catastrophic flood paleochannel (CPCB)	unidentifiable fine charcoal fragments	CAMS-82506
10,455 ± 45	01SH03; 1.55-1.57	wetland (CPCMA) in broad catastrophic flood paleochannel (CPC)	unidentifiable fine charcoal fragments	CAMS-82505
11,120 ± 60	01ST01; 6.64-6.65	relict lakebed in ice block depression (OD) located in catastrophic flood paleochannel (CPC)	uncarbonized very fine Pinaceae needles	CAMS-82605
11,470 ± 70	01ST08; 4.91-4.95	relict lakebed (LLB) in ice block depression open to catastrophic flood paleochannel	uncarbonized, unidentified wood	CAMS-82502

* ISM = Illinois State Museum