Report

Landform Sediment Assemblages in the Mississippi River Valley and Selected Tributaries between the City of St. Paul and the Minnesota-Iowa Border for Support of Cultural Resource Investigations

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16. Abstract (Limit: 200 words)

Detailed landscape sediment assemblages were mapped for the Upper Mississippi River Valley (UMV) from just downstream of the mouth of the Minnesota River Valley to the Minnesota–Iowa state line, four of its five largest west-side tributary valleys (Vermillion, Canon, Zumbro, Whitewater), and many mouths of smaller tributary valleys. The mapping provided a context for evaluating the geologic potential for buried and surface prehistoric cultural deposits in this project area. The Minnesota Department of Transportation and Federal Highway Administration developed this scope as an enhancement to the Mn/Model project in support of future cultural resource evaluations and mitigations. Mapping was accomplished digitally on-screen utilizing a range of modern and historic maps, photographic, and digital elevation data. The mapped landscape is the product of glacial meltwater discharge, catastrophic deglacial flooding, valley lake infilling, and Mississippi River and tributary alluvial processes over the course of the last thirty thousand years. Based on its geologic history, the resulting landscape mosaic has a range of landscape suitability rankings for the surface and three different depth intervals for each mapped landform sediment assemblage (LfSA). The suitability ranking of a LfSA represents a measure of the potential for geological strata to contain/preserve cultural resources with respect to depositional and post-depositional environments and geologic age.

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Landform Sediment Assemblages in the Mississippi River Valley and Selected Tributaries between the City of St. Paul and the Minnesota-Iowa Border for Support of Cultural Resource Investigations

Management Summary

This report presents results of geomorphic and landscape sediment assemblage mapping in the Upper Mississippi River Valley (UMV) from just downstream of the mouth of the Minnesota River Valley to the Minnesota – Iowa state line, four of its five largest west-side tributary valleys (Vermillion, Canon, Zumbro, Whitewater), and the mouths of many smaller stream valleys. The purpose of the report is to provide a context for evaluating the geologic potential for buried and surface prehistoric cultural deposits in this region of Minnesota. 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 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 historic Mississippi Valley maps; scanned, orthorectified and georeferenced images of USGS NAPP color infrared high altitude aerial photography; NAIP digital color aerial photography; scanned, orthorectified and georeferenced images of historic U.S. Department of Agriculture (USDA) black-and-white aerial photography; USDA digital SURRGO digital county soil maps; 10-meter interval digital elevation model; 1-meter interval LiDAR elevation model for Houston, Winona, Wabasha, Rice, Olmstead, Dodge and Dakota (6 inch interval). 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: glaciofluvial, catastrophic flood, eolian, valley terrace, floodplain, valley margin, and lacustrine. Sixteen cores were collected to obtain datable material from, and to characterize, different Landform Sediment Assemblages (LfSA's). Eight radiocarbon samples were selected and assayed at Beta Analytic, Inc. radiocarbon laboratory using standard and accelerator mass spectrometer (AMS) techniques. A history of landscape evolution was developed for the project area. LfSA's were assigned a Landscape Suitability Ranking (LSR) for the surface and three 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.

The UMV landscape seen today is the product of glacial meltwater discharge, catastrophic deglacial flooding, valley lake infilling, and Mississippi River and tributary alluvial processes over the course of the last thirty thousand years. During advance of glacial lobes into the UMV basin, outwash sand and gravel accumulated to its highest level about 20,000 years ago (yr. B.P.), then slightly incised to a main outwash plain. Tributaries that did not receive glacial meltwater were unable to keep pace with the aggradation in the UMV. Sediment dams at

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tributary mouths impounded waters creating slackwater lakes. Little is know of the following several thousands of years. Two episodes of catastrophic deglacial flooding, each perhaps involving multiple flood events, caused rapid and extensive downcutting that removed nearly all of the outwash plains from the UMV. The earlier of these floods, occurring at some time between 11,900 and 10,800 yr. B.P. was by far the larger of the two, and it incised a deep bedrock gorge in the UMV. The later catastrophic flood, occurring about 10,000 yr. B.P., rose to lower levels than the older catastrophic flood thus preserving many landforms of the earlier flood. Much of the later flood flow was contained within the bedrock gorge, and only lower parts of older, higher landforms were modified. Tributaries responded complexly by headward erosion, downcutting, and formation of multiple terrace levels. Large depositional and erosion catastrophic flood landforms formed the platform upon which subsequent Holocene landscape evolution took place. Lake Pepin is the modern remnant of a once more extensive valley lake that occupied the flood gorge following the younger catastrophic flood. The lake formed behind an alluvial fan dam deposited by the Chippewa River. It is likely that down-valley, additional valleys lakes were impounded behind other tributary alluvial fans. The early Holocene landscape was essentially within the gorge. Throughout the Holocene, the gorge filled, primarily with lake sediment. By the late Holocene, the Mississippi River had advanced into Lake Pepin, and Mississippi River processes had already overwhelmed other lakes down-valley. Lateral flood basins filled, largely with enormous crevasse splay systems, but also with natural levees, bars, and sediment provided by tributaries. Tributary streams entered the UMV and deposited alluvial fans. Some of the larger streams coursed through flood basins, creating their own LfSAs. Catastrophic flood landforms that were lower on the landscape were buried by valley margin alluvial fans and colluvium, as well as Mississippi River alluvium. Historic landscape changes and construction of the lock and dam system led to a widespread sediment veneer on floodplain landforms that buries the prehistoric surface, and a series of landforms that entirely Historic in age.

The resulting mosaic of landscapes and landforms exhibits a range of landscape suitability for the burial and preservation of prehistoric cultural deposits. Sediment assemblages of outwash terraces, higher valley terraces in tributaries, and catastrophic flood LfSAs are essentially too old to have any buried cultural deposits; Paleoindian and younger cultural deposits will be surface or near-surface manifestations. In the case of the youngest catastrophic flooding, flood depositional environments simply were uninhabitable. The oldest cultural deposits on surfaces formed during this flood will be Early Archaic in age. Burial of cultural deposits on these terrace surfaces is possible as there are areas of eolian dunes, at least some of which are late Holocene in age, and colluvial aprons along the valley margin where many of the older, higher landforms are preserved. Large volumes of fill in the Mississippi Valley consist of lake sediment which while conducive to burial and preservation of prehistoric cultural deposits, would be unfavorable for settlement. The lake – land interface, however, which would have shifted through the Holocene as the valley filled and tributary fans developed, is judged a key location for burial and preservation of prehistoric cultural deposits. Burial of Archaic would be quite deep, with burial of younger cultural deposits at progressively shallower depths. The late Holocene floodplain was still fairly poorly drained. Natural levees, relict bars and high parts of crevasse splays would have been the most favorable locations for late prehistoric settlement. However, most of these surfaces are buried to varying depths by alluvium that is post-Euroamerican settlement in age. Thus, surface sites are rare in the UMV floodplain, but the geologic potential for sites as old as perhaps Late Archaic buried in floodplain LfSAs is considered moderate to high.

1 Introduction

The Minnesota Department of Transportation (Mn/DOT) requested an assessment of the geomorphology and landform sediment assemblages (LfSAs) of that part of the Upper Mississippi River (UMV) between St. Paul southward to the Minnesota–Iowa state line, as well as the four largest unmapped tributaries in Minnesota (Figure 1). From north to south, these tributaries are the Vermillion, Cannon, Zumbro and Whitewater rivers. The northern project boundary picks up where mapping of the Minnesota River Valley (Hudak and Hajic 1999) and Mississippi River Valley (Hajic 2002) immediately upstream of the current project reach left off. The valley of the largest tributary in Minnesota, the Root River, was mapped previously as part of the original Mn/Model (Hudak and Hajic 1999). The assessment is an enhancement to the geomorphic contributions of Mn/Model (Hudak and Hajic 1999). For several reasons, the project reach of the UMV has been of some concern for some time. Much of the floodplain sediment assemblage is capped by a sediment increment that is post-Euro American settlement in age, thus prehistoric cultural deposits have a good chance of being in buried contexts. Tributary valley mouth areas, crossed by Highway 61 and lesser roads bridging tributaries, are often foci of prehistoric occupation. These locations are rapidly developing along the UMV south of the Twin Cities. Results of the investigation will benefit planning and environmental assessment, particularly in the evaluation of prehistoric cultural resources for which the investigation is designed, but also for other engineering and science applications as well.

To facilitate reading this report, please see Appendix A for a "List of Abbreviations, Acronyms, and Symbols," and Appendix B for a "Glossary of Terms." Appendix C will also assist the reader and end-user to understand the model's mapping unit codes, which are the definitions and shorthand mapping symbols (i.e., mapping labels) for each database field. Appendix D contains the core descriptions (and their GPS locations) used to help ground truth certain landform sediment assemblages. Appendix E and Table 1 both contain all the pertinent information related to the radiocarbon assays conducted for the ground-truthing part of this project. Table 2 contains all the pertinent information related to the optical spectral luminescence assays conducted for the ground-truthing part of this project.

2 Objectives

The objectives of the investigation are to:

- Build a GIS database for the project area useful for geomorphic mapping;
- Digitally 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 geologic potentials for the location, burial and preservation of intact prehistoric archaeological deposits in terms of Landscape Suitability Rankings (LSR's) for LfSA's.

3 Quaternary Geologic Overview

The Mississippi–Zumbro project area includes that reach of the Upper Mississippi River Valley (UMV) from St. Paul to the Minnesota–Iowa state line. Late Wisconsin glacial ice entered the northernmost part of the project area, and the UMV drains a largely collapsed ice landscape of multiple glacial lobes to the north of the project area. The project area also includes the main stems of the four largest west-side tributaries, the Vermillion, Cannon, Zumbro and Whitewater Rivers, as well as the mouths of numerous tributary valleys of lower order (Figure1). These west-side tributaries largely drain an eroded, bedrock-controlled landscape that had already been glaciated well before the Wisconsin ice entered Minnesota. However, in the past, all but the southernmost of these four large tributaries carried glacial meltwater at some time during their history.

The project area was impacted by glacial lobes derived from distinct eastern (Labradorean) and western (Keewatin) source areas of the Laurentide Ice Sheet in Canada. The Lake Superior Lobe (and related sublobes) advanced southwestward through the Lake Superior basin, scouring iron- and copper-rich bedrock that imparts a reddish brown hue to its glacial drift. Lake Superior Lobe till is further characterized by sandy loam diamicton textures and an absence of Cretaceous shale clasts (Hobbs et al. 1990). A balance between ice flow and melting was achieved to produce the St. Croix end moraine in and around the Twin Cities metropolitan area sometime between 20,000 and 15,000 yrs. B.P. (23,950 and 18,500 cal. yrs. B.P., Mickelson et al. 1983). The St. Croix moraine is just south of a marked bend in the Mississippi Valley and within the northern limits of the project area. Advancing into the project area, ice overrode multiple generations of pre-existing and filled bedrock valley segments (Schwartz 1936, Bloomgren et al. 1990, Blumentritt et al. 2009). Down-valley from St. Paul, the modern UMV re-utilizes older bedrock valley reaches, although the bedrock valley morphology has been altered by Late Wisconsin and earliest Holocene catastrophic floods. Meltwater emanating out from the Lake Superior Lobe flowed down the contemporaneous version of the Mississippi Valley, and presumably outwash terraces aggraded. Ultimately, the St. Croix moraine was left behind by the Lake Superior Lobe, both ice-cored and stagnating.

The slightly younger Des Moines Lobe advanced southward through the Red River lowlands of western Minnesota, then southeastward, building lateral moraines in western and northern Dakota County, and then southward into Iowa. Meltwater from the eastern lateral flank of the lobe drained down the Vermillion, Cannon, and North and Middle Forks of the Zumbro River to their contemporaneous versions of the Mississippi Valley. As the Des Moines Lobe of ice in Iowa was stagnating (Kemmis 1991), the Grantsburg Sublobe advanced northeastward, just north of the Twin Cities, about 11,900 C^{14} yrs. B.P. (13,770 cal. yrs. B.P.; Wright and Rubin 1956, Meyer 1998, Hajic et al. 2009). Des Moines Lobe till is characterized by loam to clay loam diamicton textures, gray (fresh) to yellowish brown to olive (oxidized) colors, and sparse to abundant Cretaceous shale clasts (Hobbs et al. 1990). Moraines, till and outwash from advances of these three lobes occur in Dakota County.

While glacial events contributed outwash fill to the Mississippi and other tributary valleys, deglacial events were instrumental in shaping landscape elements of the valleys, as well as establishing the baseline for Holocene landscape evolution. These deglacial events resulted in development of buried paleolandscapes, which are critical to understanding the location, integrity and age of buried prehistoric cultural deposits, if present. Configuration of the modern Minnesota River Valley is primarily the result of one or more catastrophic floods emanating from Lake Agassiz, an enormous proglacial lake that occupied the Red River lowlands following retreat of the Des Moines Lobe. Lake Agassiz drained southward through a broad spillway cut through the Big Stone Moraine (of the Des Moines Lobe) which forms the drainage divide between the Minnesota and Red rivers. On geomorphic evidence, Hudak and Hajic (1999) concluded that the incised Minnesota Valley formed by catastrophic flooding, sharing many landforms characteristic of spillway valleys formed or modified by deglacial catastrophic floods (Kehew and Lord 1986). Minnesota Valley-forming catastrophic flood(s) pre-date 10,400 C^{14} yrs. B.P. (12,270 cal. yrs. B.P.) based on several radiocarbon ages from the base of valley-bottom alluvial fans and underlying fluvial deposits in the New Ulm and Mankato vicinities (Hudak and Hajic 1999, Hudak and Hajic 2005). Alluvial fans were deposited along the length of the Minnesota Valley as tributaries incised in response to the rapid cutting. Fisher (2003) used sedimentology and radiocarbon ages from cores to determine that the spillway occupied by Big Stone Lake was initially abandoned at its maximum depth of erosion around 10,800 C^{14} yrs. B.P. (12,830 cal. yrs. B.P.). Lake Agassiz discharges later shifted to eastern and then northwestern outlets. The age of initial catastrophic flooding that carved the Minnesota Valley and impacted the Upper Mississippi Valley remains open to question, but had to occur after the advance of the Grantsburg Sublobe, or about 11,900 C^{14} yrs. B.P. (13,770 cal. yrs. B.P.) Fisher (2003) concluded that the spillway through the Big Stone Moraine was effectively inactive between about 10,800 (12,830 cal. yrs. B.P.) and at least 9,920 C^{14} yrs. B.P. (11,270 cal. yrs. B.P.) as indicated by: (1) dated lacustrine sediment from Big Stone Lake, (2) valley-bottom radiocarbon ages from the Minnesota Valley (Hudak and Hajic 1999), and (3) the dated deciduous forest elements from the Lake Agassiz basin near Moorhead that indicated Lake Agassiz was north of this location at a relative low stand (Yansa et al. 2002) during the Moorhead Phase (Fisher 2003, Fisher et al. 2008). Additional radiocarbon ages that lend support to this interpretation, particularly the ages of Yansa et al. (2002) and Yansa and Ashworth (2005), come from approximately 17 km (10.6 miles) farther north of Moorhead in the Lake Agassiz basin near Georgetown, MN, (Hudak and Hajic 1999) and elsewhere in the basin (summarized in Fisher et al. 2008).

The southern outlet was reactivated sometime between 9,900 and 9,400 C^{14} yrs. B.P. (11,265 and 10,600 cal. yrs. B.P.); however, initiation of this second phase of discharge most likely occurred during the last few centuries of this interval with little if any further incision of the Big Stone Lake spillway (Fisher 2003). Hudak and Hajic (1999) documented the preservation of older Minnesota Valley-bottom alluvial fans and terraces (ca. 10,330-10,400 C^{14} yrs. B.P., 12,105-12,360 cal. yrs. B.P.) that lack evidence of catastrophically-carved paleochannels. This lack of catastrophic flooding evidence indicates that subsequent Holocene-aged discharges were orders of magnitude less than the earlier discharge that carved the Minnesota Valley. The latter phase of flow(s) from Lake Agassiz must have been a relatively low discharge, perhaps with seasonal fluxes.

Upstream from the MRV/UMV confluence, the Mississippi River was mostly a broad, braided outwash stream that drained along the inner St. Croix glacial end moraine. Later, the UMV was supplied by outwash carried by the Grantsburg Sublobe and Des Moines Lobe meltwaters. Hajic

(2002) suggested that the Mississippi River may have debouched across the Anoka Sand Plain at one point, and may have fed an earlier course of the St. Croix River until the Minneapolis North Gap opened sometime between 11,400 and 11,800 C^{14} yrs. B.P. (12,270 and 13,690 cal. yrs. B.P.). Catastrophic flow from Lake Agassiz down the MRV was augmented by the Mississippi River at Fort Snelling and followed a new course to St. Paul, where it entered an old valley of the Mississippi River, forming a waterfall over flat-lying Paleozoic rocks. The resulting waterfall migrated upstream past the current location of St. Paul, and as it passed the confluence with the Mississippi River at Fort Snelling about 10,800 C^{14} yrs. B.P. (12,830 cal. yrs. BP) the waterfall divided into two branches (Wright, H.E., Jr., personal communication). The Mississippi branch migrated upstream as St. Anthony Falls, causing third-order falls to develop along its smaller tributaries, and remains visible near downtown Minneapolis (Wright 1972). The Minnesota River branch migrated upstream until it reached the western edge of the Paleozoic caprock that maintained the waterfall (Wright 1972).

Glacial Lake Duluth formed in the western Lake Superior basin during retreat of the Lake Superior Lobe (Emerson Phase). Major outlet valleys were the Kettle River in the Duluth vicinity, and the Brule River in Wisconsin. These two rivers merge to form the St. Croix River. The modern St. Croix River Valley (SCV) occurs at two elevation tiers or levels that are separated by Taylors Falls, and enters the UMV in our field trip area. Geomorphic evidence indicates that catastrophic flooding from Glacial Lake Duluth simultaneously down the Kettle and Brule river valleys shaped the current SCV (Hudak and Hajic 1999, Hajic and Hudak 2005). Evidence supporting this catastrophic origin includes the Taylors Falls' potholes, a collection of more than 100 holes drilled by current-driven sands and gravels into basaltic bedrock (Alexander 1932). Additionally, the highest terrace level of the upper tier, which is composed of a suite of cut marginal flood channels in terrace positions that are buried by up to eight meters of Holocene-aged peat (Hudak and Hajic 1999, Hajic and Hudak 2005); and the floor of the lower tier, which underlies Lake St. Croix (Lund and Banerjee 1985), both share similar bracketing ages around the Pleistocene–Holocene transition, even though the two levels are separated by at least 48 m elevation difference. Radiocarbon ages from the: (1) lower tier's floor and upper tier's basal peat wood sample of the SCV (Hudak and Hajic 2002, Hajic and Hudak 2005); (2) wood in basal peat beds on buried bedrock ledges that flank the inner UMV channel (data presented herein); (3) basal fill within the inner UMV channel (data presented herein); and, (4) related marker bed in the UMV and central Mississippi Valley (Hajic and Bettis 1997), indicate that the last catastrophic flood(s) most likely date(s) sometime between 9,900 and 9,700 C^{14} yrs. B.P. (11,265 and 11,175 cal. yrs. B.P.), but could be as old as about 10,100 C^{14} yrs. B.P. (11,715 cal. yrs. B.P.) Flood magnitude did not approach that of the earliest catastrophic flood from Lake Agassiz that cut the UMV down-valley from Fort Snelling, and much of the flood activity in this current project area's reach of the UMV was erosional and inset below both the lowest subaerial terrace surfaces and buried bedrock benches within the bedrock gorge (discussed herein below). Waters from Glacial Lakes Aitkin and Upham, large lakes associated with the retreat of the St. Louis sublobe of the Superior Lobe, also may have augmented this flood although the detailed timing of their existence and demise has not been well developed (Farnham et al. 1964). Slightly earlier lakes, predecessors of Glacial Lake Duluth (e.g. Glacial Lake Lind, Johnson et al. 1999), would most likely have contributed discharge down the St. Croix Valley (Blumentritt et al. 2009), although the form and location of the valley at that time would have differed from that of today.

The St. Croix Valley flood set the stage for Lake Pepin in the UMV (Winchell and Upham 1884, Zumberge 1952, Blumentritt et al. 2009) and Lake St. Croix in the lower SCV, both riverine lakes in our project area. Blumentritt et al. (2009) define different Lake Pepin phases, differentiated largely by the growth of tributary fan deltas into the river lake. Floodplains eventually developed as parts of Lake Pepin filled, although Lake Pepin is still a substantial water body.

4 Methods

Methods follow those outlined for Mn/Model geomorphological investigations (Hajic 2002 as modified from Hudak and Hajic 1999), greatly modified to take advantage of methodological, technical and software advances over the last decade. Available relevant literature and source data were assembled and assessed for utility toward mapping in the GIS and evaluating geologic models.

4.1 Data Acquisition

Multiple GIS base map datasets were constructed for the project. Refer to the GIS metadata for data lineage and project coverage information.

Both historical and modern color-infrared aerial photography mosaics were generated from individual 9x9-inch photo frames, to create seamless aerial photography base map layers.

All basemap layers were projected to the UTM (Universal Transverse Mercator) Zone 15 coordinate system, with a horizontal datum of NAD83 (North American Datum 1983). All units are established in meters.

4.2 GIS Workflow and Hardware / Software Setup

A combination of both desktop GIS and server-based GIS processing was utilized to complete the project. Due to the length of the project, the range of versions of ESRI's (Environmental Services Research Institute) ArcGIS Desktop, ArcSDE, and ArcGIS Server spanned from versions 9.3 to 10.1.

GIS desktop operations were performed on HP workstations with dual LCD displays. Server-based GIS operations consisted of versioned geodatabase replication, web-based GIS hosting (for project status site), and nightly geodatabase backups.

All features for the geomorphology layer were constructed through heads-up digitizing over various basemap layers, alone and in combinations, at a minimum of 1:24,000 scale. Topology rules were developed and utilized during every editing session to detect and repair gaps and overlaps between features throughout the extent of the geomorphology layer.

4.3 Custom Map Symbol Assignment Tools

To promote efficiency, accuracy, and ensure that the geomorphologists could focus their efforts on mapping instead of attribute management, a set of custom GIS tools developed during the previous Mn/Model enhancement (Hajic et al. 2009) were utilized. The custom GIS tools utilize lookup tables and drop-down box user interfaces to nearly eliminate manual typing, and automate the task of assigning and creating new map symbol records as much as possible. This concept also guarantees uniqueness of new map symbols and code key values, and at the end of the project, makes it easier to extract all new attribute records created during the project.

4.4 Digital Mapping

Heads-up digital mapping was conducted. Mapping covered the UMV in Wisconsin, albeit not at the same level of detail, to have a full valley-wide picture of the LfSAs. In general, geomorphic mapping proceeded by layering various coverages in various degrees of transparency over a DEM or shaded relief base; and, starting midterm through the project, LiDAR was added for most of the project area. Layers were toggled on and off as needed. Utility of the various photographic based layers varied by county and by landscape or landform. The earlier aerial photography, in particular, revealed detail in tonal contrasts with geomorphic implications that have since been lost with urbanization. However, margins of wetlands and lake levels vary between the historic photography and the later CIR (color infrared) and color photography. LfSA polygons were tagged using the custom tools. The final geomorphology coverage had a final topology validated, and was smoothed, then edge-matched with mapping from earlier projects, and trimmed to the project boundary. Edge-matching with previous digital mapping was completed at the end of mapping. Advances in methods, techniques, available data layers (particularly LiDAR) and interpretations did cause discontinuities at adjoining project boundaries and sometimes within this project. Mapping from the various adjoining projects easily can be updated to resolve these discontinuities at a later date, as can any discontinuities within this project when their local databases are updated.

Edwin Hajic mapped the UMV, Zumbro, Whitewater, and lowest reach of the Vermillion valleys. Curtis Hudak mapped the bulk of the Vermillion and Cannon valleys.

Two different people digitally proofed the geomorphic mapping for map labels, geomorphic location, and geologic continuity. The Map Unit (LfSA) Field Code Key was also updated (Appendix C).

4.5 Digitally-Assisted Terrace Correlation

The correlation of terraces on USGS 7.5' topographic maps and especially down extensive lengths of valleys is fraught with problems, particularly in valleys where multiple terraces are represented and terrace gradients can be steep. To improve on terrace correlations, Spatial Analyst software was utilized to aid in the construction of terrace profiles. Plan-view arcs were laid down over terrace polygons as a shape file, then digitally draped over the 10m DEM and rotated to project terrace remnant profiles in the vertical dimension. For most terraces, correlation of terrace remnants was relatively straightforward. In some steeper sections, a greater degree of interpretation is still required. An attempt was made to create one system of terrace correlation that includes both tributaries and the UMV. It is expected that some of the tributary terraces may be off by one or two terrace levels, particularly terraces that are older and those that pass through steeper tributary valley reaches. The analysis was conducted by Hajic.

4.6 Sediment / Soil Coring and Analysis

Because subsurface investigations would be limited, and the project area is large, the subsurface coring program targeted several landform or landscape settings that are key to (1) defining and understanding the glaciofluvial terrace baseline that underpins subsequent landscape evolution;

and, (2) dating the youngest deglacial flood and its impact on subsequent Holocene landscape evolution in the UMV and its tributaries. Different landforms were sampled in an attempt first and foremost to collect organic remains that would provide minimum ages or actual ages for relevant landform sediment assemblages (LfSAs). However, it was known that such remains would be scarce in the glaciofluvial LfSAs, so OSL dating was introduced for the first time into Mn/Model. Core locations were recorded with a Trimble GeoExplorer XH GPS unit.

Fifteen solid continuous sediment–soil cores were collected with a hollow-stem drill rig. Recovery was variable as the sand of glaciofluvial sediment assemblages tended to "bridge" in the core liners, thus preventing full recovery. Liners were extracted from the barrel, capped and labeled. Cores were removed from the liners, split longitudinally along natural planes of fracture and cleavage, and described utilizing slightly modified standard pedologic and sedimentologic techniques and terminology (Schoeneberger et al. 2002). Hudak oversaw the coring; and his descriptions are in Appendix D. Hudak also oversaw the graphic sediment soil logs that were constructed from the descriptions, and utilized in cross-sections.

Generally small samples of very fine organic material were extracted from cores. In some cases, sediment samples were washed through nested sieves to recover fine organic detritus. Residual organic material was rinsed with distilled water, air dried, and shipped to Beta Analytic for assay using the AMS technique. Radiocarbon laboratory reports are presented in Appendix E.

Original or resampled core segments were submitted to the University of Illinois, Chicago, OSL lab for assays.

5 Landscapes and Landform Sediment Assemblages

Seven landscapes are recognized within the mapping limits of the project area valleys. Landscapes and the major landform sediment assemblages (LfSA) within each landscape are outlined below, from oldest to youngest to the degree possible. The reader is advised that this text is meant to help interpret the GIS digital model produced as part of this project. Hardcopy figures can neither adequately convey our interpretations, nor the geographic expanse of each LfSA or landscape. Said differently, think of this Section 5 as a long "figure caption" that is helping to explain the model displayed upon your computer screen.

5.1 Glaciofluvial Landscape

The Glaciofluvial Terrace Landscape in the project area reach of the UMV is divisible into three groups of terraces. The highest and oldest Glaciofluvial Terrace group consists of the OT16:22 through OT23:22 LfSAs. These terraces only are clearly resolved upstream of the Vermillion River Valley where they are inset below the level of the St. Croix Moraine. A rapid increase in slope in the upvalley direction suggests that this terrace group probably graded to the crest of the St. Croix Moraine and its early wasting phases. Downstream, they apparently grade to the OT15 terrace, but the sediment assemblage and temporally correlative surfaces almost undoubtedly underlie the OT15 terrace and an increment of outwash down-valley from the Cannon Valley mouth. One LfSA represents a strath terrace (OST:20:22). Locally, very thin loess may be discontinuously present, but only one LfSA with loess was mapped (OTL20:22). Several remnants of the OT16:22 LfSA are scoured by younger, probably catastrophic, flooding (OTF16:22). Paleochannels are rarely evident (OPC17:22).

The Vermillion River Valley's highest mapped terrace is the OT20:22 LfSA, which has been called the Rosemount Outwash Plain (ROP) by Hobbs et al. (1990). To the north of the Vermillion River, large unmapped remnants of the OT20:22 LfSA occur between the Vermillion River and Rich Valley, where it gently descends from the St. Croix end moraine southeastward toward the Mississippi River. To the south of the Vermillion River, large remnants occur between the Vermillion River and the dissected bedrock terrains further to the south. Terrace margins range from smooth to irregular, and tend to be dissected by short, steep drainage ways. The terrace (or plain) is relatively flat to gently rolling, with few intermittent drainage ways that drain or cross the OT20:22 surface that remain undifferentiated in the mapping. The underlying sediment assemblage consists of stratified glaciofluvial sand and gravel. Several scoured surfaces related to the OT20:22 are represented at the north end of the scoured Vermillion River Valley landscape. One small remnant close to the mouth of the Vermillion River Valley has a thin veneer of coarse grain glaciofluvial material over bedrock (OST20:22). One slightly higher remnant (OTL20:22) is mantled by Late Wisconsin loess suggesting that this surface was not fully scoured.

There is a series of Terrace LfSAs that lie in elevation between the two outwash plains (i.e., the ROP and the geomorphically lower Vermillion Outwash Plain [VOP; OT15:22 LfSA] mentioned further below) that define the Vermillion River Valley. These intermediate terrace levels are most likely eroded into the older and higher OT20:22 LfSA (ROP). As a result, these terraces are likely closer in age to the VOP than the ROP, but that is yet to be determined. On the north side of Rich Valley, a nearly continuous, but dissected, bench (OT18:22) is cut into an OT20:22 remnant. The OT17:22 LfSA is represented by a series of small remnants. Most rise above the VOP in the middle to upper reach where they are mostly represented at the terminal ends of dissected spurs eroded into OT20:22 remnants. Several other remnants are streamlined, and surrounded completely by the VOP. One isolated remnant occurs within an arc cut into the OT20:22 surface. A second isolated remnant occurs at the head of one of the sluiceways. Given its position relative to the ice front, the latter example may be an aggradational terrace.

The OT19 terrace is represented in the lower-upper reach of the North Fork Zumbro River and upper reach of the Middle Zumbro River. This terrace occurs as both narrow slivers adjacent to uplands (sometimes as a lower step extension to adjacent Late Wisconsin erosion surfaces), and broader expanses of less steeply sloping terrace remnants that also abut uplands. The sliver remnants exhibit a range of sediment assemblages. Loess, redeposited loess, or loamy colluvium reflective of valley margin environments can be less than a meter thick to greater than two meters thick. These sediments overlie loam diamicton or outwash. Broader remnants are underlain primarily by more than two meters of coarse grain glaciofluvial deposits.

Along the north side of Rich Valley there is a narrow, dissected bench (OT18) inset into OT20. The OT18 surface is most likely cut into the older glaciofluvial sediment assemblage associated with the OT20 surface. OT18 is also mapped in the North Fork Zumbro River.

The next lower and younger terrace suite consists solely of the most extensively preserved terrace in the UMV reach covered by the project reach, the OT15:22 terrace LfSA. Several facies of the OT15:22 terrace are preserved. The OT15:22 terrace forms the Vermillion Outwash Plain (VOP, also mentioned above) in the Vermillion River Valley, but does not appear upstream of this location. At least two substantial remnants of the "outwash facies" are preserved in the main Mississippi valley. One occurs just upstream of the mouth of the Black River, and the other at Lacrosse, WI. Both of these examples have tributary valley floors that grade to the OT15:22 surface, and were therefore not further incised by subsequent downcutting. The OT15:22 outwash facies in the main Mississippi valley has been otherwise mostly removed by subsequent downcutting and valley widening during catastrophic flooding, whereas this same terrace in the tributary valley mouths is almost ubiquitously preserved, regardless of tributary stream order. The terrace in this tributary valley mouth position is often underlain by outwash, but a short distance up the tributary, it is mantled by often-thick slackwater lake silts and clays, including distinct reddish-brown clay sourced to the Lake Superior Basin. The "slackwater (lake sediment) facies" is in effect a thick veneer atop the actual OT15:22 sand surface. Silt and clay accumulated in this position because tributary aggradation lagged behind outwash aggradation in the main valley. Thus, the OT15:22 surface, like upper reaches of many outwash terraces, decreases in age in a downstream direction.

In the Vermillion Valley where the OT15:22 LfSA is extensive, it is pocked by ice-block meltout depressions with varying thicknesses of fill (OD:22; OD<<22: OD>>:22) and wetlands (ODMA<<:22; ODMA>>22), ponds (ODPN:22) or lakes (OLN:22). Paleochannels are rare (OPC15). At the junction of Rich Valley with the Vermillion Valley, there are relatively fresh, angular-looking, and shallow ice-block meltout depressions (ODR:22) with perpendicular internal ribs (ODP:22). Another rather unique feature in the same vicinity is an apparent small esker swarm with a distributary form (OEK:22) associated with a possible alluvial fan (OAF15:22).

Locally, the OT15:22 LfSA is modified by the deposition of eolian dunes (OTE15:22); scour by younger floods (in the mouth of the Vermillion Valley) (OTF15:22); and, by formation of wetlands with thick peat (OTMA>>15:22). Associated paleochannels (OPC15:22) are rare.

Remaining terraces (OT14:22 through OT11:22 LfSAs), all inset below the level of the OT15:22 LfSA, constitute the third glaciofluvial terrace suite. They occur primarily in the tributary valleys that received outwash. The OT14:22 LfSA often occurs within the mouths of tributaries to the UMV where it may have been slightly scoured by catastrophic flood waters. Surface modifications include a small scattering of eolian deposits (OTE14:22), flood scouring (OTF14:22), a braided channel surface pattern (OTB14:22), limited sediment veneer (OT<<14:22), and paleochannels (OPC14:22). Occasionally, a bar form is expressed (OB14:22).

5.2 Catastrophic Flood Landscape

The highest(and likely oldest) catastrophic flood landforms in the project area are located between the UMV and lowest reach of the restricted Vermillion Valley where they rise above the Vermillion Outwash Plain (VOP) and scoured remnants of the Rosemount Outwash Plain (ROP). Multiple landforms are represented by very few remnant examples of each landform. The landforms extend over a limited range of elevations, but appear to be genetically related. They are inset slightly below the single remnants of the OST20:22 and OTL20:22 LfSAs, and it is possible that both of these remnants could in fact belong to the Catastrophic Flood Landscape. Several irregularly shaped erosional bedrock exposures rise above all other local geomorphic surfaces in the broad mouth of the Vermillion River Valley. Bedrock is shallow to very shallow on the sideslopes of these surfaces that face up-valley of the terraced headlands along the UMV and lowest reach of the restricted Vermillion Valley.

There is one remnant of the CST<20:22 LfSA and it occurs immediately above the Mississippi valley margin sideslope that faces up-valley. Several short eroded spurs descend northward and are included in this mapped unit. Thin, coarse grain alluvium overlies bedrock on the highest, broadest surfaces, and spurs tend to be formed on bedrock with little or no sediment mantle. Immediately south of this remnant and the loess-mantled OTS20S:22 LfSA is what appears to be a narrow paleochannel that occupies a complex saddle between bedrock highs and other high terrace remnants. Greater than two meters of coarse alluvium covers most of the saddle.

Two different remnants, the slightly higher CER<20:22 and slightly lower CER20:22, when combined form an erosional residual. The CST20:22 remnant is down-flow of the CST<20:22 remnant. The down-flow part of the erosional residual is underlain by greater than two meters of coarse grain alluvium, whereas less than a meter of sediment overlies bedrock on the higher, up-flow part.

There is a series of terrace remnants in the elevation range of the lower part of the erosional residual and at slightly lower elevations. These terrace remnants (CTF20:22) show evidence of being scoured and streamlined by fluvial activity, presumably associated with the same catastrophic flooding that shaped higher surfaces. They are underlain by sometimes thick coarse alluvium. All but perhaps the uppermost meter or so is interpreted to be part of the Rosemount Outwash Plain sediment assemblage (OT20:22), except for the easternmost remnant that has a greater elevation range and includes higher flood-scoured hill slopes leading up to higher surfaces.

Younger catastrophic flood terraces occur in the UMV inset into high outwash terraces. They occur along the valley wall as well as within central parts of the valley. Catastrophic features include flood bars, marginal channels (paleochannels), strath surfaces and undifferentiated terraces. While all of these features are identified as multiple generational according to terrace mapping convention, and they across a range of elevations, they are considered to be geologically the same age as incision during catastrophic flooding is rapid. The earliest and largest catastrophic flood(s) are related to outflow from Glacial Lake Agassiz, and all but the lowest catastrophic flood features are attributed to this event. Younger, lower catastrophic flood forms are attributed to the St. Croix Valley flood, but this flood could have modified some earlier flood landforms.

Catastrophic flood bars at various elevations (CB3:22, CB4:22, CB5:22, CB7:22, CB8:22; CB9:22) are often quite large streamlined forms that occur detached from the bedrock valley wall. They are often flanked by margin flood paleochannels. Several examples have pronounced dunes on their surface, sometimes related to the positioning of west-side tributary valley mouths. Eolian deposits on catastrophic flood terraces are probably underrepresented in the LfSA mapping. Catastrophic flood channels, or marginal channels, often flank the flood bars. Those not associated with bars are usually identified as paleochannels, rather than terraces, when both sides of a channel can be defined. Undoubtedly, some of the surfaces mapped as catastrophic flood terraces functioned as channels, but were subsequently incised during later stages of flow removing one of the channel walls. Paleochannels occur at a range of elevations (CPC3:22; CPC4:22; CPC5:22; CPC7:22; CPC8:22; CPC9:22; CPC10:22). In a few locations, catastrophic flood paleochannels are occupied by wetlands with greater than two meters of peat (CPCMA>>1:22; CPCMA>>3:22; CPCMA>>5:22). Several more are inundated (CPCW3:22; CPCW5:22; CPCW7:22). A few remnants of lower paleochannels have a "Type O" overbank veneer (CPCO3:22; CPCO4:22).

Strath terrace surfaces with little sediment veneer are few (CST<3:22), but many of the valley margin catastrophic flood terraces (CT3:22; CT4:22; CT5:22; CT7:22; CT8:22, CT9:22; CT10:22) are undoubtedly underlain by bedrock strath surfaces as the UMV was certainly widened during at least the earlier Glacial Lake Agassiz flooding. Again, eolian mantles are probably more widespread than are mapped (CTE7:22). One flood terrace remnant has an associated wetland with peat greater than two meters thick (CTMA>>5:22).

5.3 Eolian Landscape

In addition to eolian modification of Catastrophic Flood terrace surfaces, there are eolian dunes (EED:22) in the lower Vermillion River Valley. One set of dunes clearly has a local source as it forms a line along the top of the east side of Sand Coulee, found southeast of and close to the City of Hastings.

5.4 Valley Terrace Landscape

The Valley Terrace Landscape Sediment Assemblage is best represented in those valleys that did not receive outwash. The Valley Terrace Landscape is limited to the lowest terrace surfaces in those valleys that did receive outwash. This landscape likely has up to several terrace sediment assemblages that are Holocene in age, but higher remnants are likely pre-Holocene in age as well.

Four of the five highest terraces are represented in the Whitewater River Valley. Remnants are represented in all but the lower reach, although remnants are most numerous in the bedrock meander and upper reaches of the North and Middle Forks. Within the bedrock meander reach, remnants of the VT25 and VT24 surfaces occur within the meander cores, inset below the adjacent uplands, including some older erosion surfaces, in a gently to steeply sloping, step-wise manner. Each of these two terraces can incorporate multiple geomorphic surfaces. The VT25 terrace is also present in lower reaches of some tributaries of at least the bedrock meander reach. TheVT25 and VT24 surfaces can be erosion surfaces formed on bedrock, residuum or pre-Wisconsin till, with or without preservation of buried geosols; strath terraces; or, fluvial terraces that accumulated under severe climatic conditions. Higher surfaces can be mantled with Wisconsin loess that ranges from greater than two to less than one meter thick. Lower surfaces tend to be mantled by loamy alluvium or colluvium. The surfaces are clearly associated with bedrock-cored meanders. The few remnants of the VT25 surface that occur in the middle reach are situated together in a slight arcuate incision that is cut into the uplands. These VT25 surfaces are underlain by coarse-grained alluvium.

There are several (4) paleochannel remnants (VPC25) associated with the high surfaces of VT25 in the bedrock meander reach of the Middle Fork of the Whitewater River and along the Whitewater Valley margin just downstream of the confluence of the North and Middle Forks. Two of the paleochannels are of tributaries preserved within the lowest reach and mouth of side valleys. The other two remnants occur as slivers of meander channel along the valley wall. There is one paleochannel remnant (VPC24) associated with the VT24 surface and it occurs in the lowest reach of a tributary.

VT23 is mapped in the upper reach of the MF. It is also present, but unmapped, flanking the upper reach in the North Fork. Included are a number of broader remnants that are more extensive than mapped. VT23 remnants abut the valley wall and are inset below the level of stepped erosion surfaces. Multiple surfaces are represented by the VT23 map unit, but fewer than are covered by the VT25 and VT24 map units. For the most part, the main VT23 sediment assemblage consists of greater than two meters of loess over alluvium, buried strath terraces, or very late erosion surfaces. Younger components are overlain by thinner increments of loess and/or loess-derived colluvium. There are a few remnants that consist of coarse-grained alluvium.

Map Units VT22 and VT21 occur in the lowermost part of the upper reach, and extending across the transition into the uppermost part of the bedrock meander reach in the North Fork. One VT21 remnant is mapped in the uppermost part of the bedrock meander reach of the Middle

Fork. Within the bedrock meander reaches, almost all remnants are narrow and occur on the nose of meander cores, with only a few along cross-over segments between meander core nose-slopes. In these reaches, the VT21 remnants tend to be slightly wider on average. Where present in the upper reach, these terraces are inset into low, loess-covered upland surfaces that include some broad expanses of coarse grain alluvium of unknown age beneath the unmapped VT23 surface. Remnants are narrow to slightly broader when opposite higher upland nose slopes.

In both reaches, VT22 remnants are underlain by up to over two meters of loess and loess-derived colluvium. Some remnants are cored by bedrock strath terraces or residual soils on bedrock. In contrast, the VT21 remnants in the upper reach are underlain by coarse alluvium with higher parts underlain by loess or redeposited loess. Lower parts can have a soil shallowly buried by a terrace veneer sediment. VT21 remnants in the uppermost bedrock meander reach have a loess mantle suggesting underlying sediment assemblages similar to VT22.

VT15 is present in the middle and lower reaches of the Whitewater River Valley, and the terrace is more extensive than mapped, extending into the lower reaches of Whitewater Valley tributaries. Where present, the terrace abuts or is buried by valley margin colluvial slopes. Remnants are often preserved within arcuate segments of valley walls, particularly in the middle reach. The valley wall arcs are probably relicts of the earlier bedrock-cored meandering Whitewater River. VT15 remnants tend to be more extensively preserved in the lowest part of the valley.

Sediment assemblages associated with the VT15 LfSA vary from the middle reach to the lower reach, reflecting the influence of outwash aggradation in the UMV as well as likely eolian additions. In the middle reach, the sediment assemblage consists of either loess-derived silt loam alluvium or slackwater lake deposits, or coarse grain sediment. The dominant coarse textured soil that is mapped on the VT15 surface by the USDA is the Plainfield series, a series interpreted in the official description to have formed in 'sandy drift.' This sediment assemblage when found in the Whitewater River Valley, is interpreted as either coarse-grained alluvium; eolian sand greater than two meters thick; or eolian sand over coarse-grained alluvium. Apparently there is no outwash of Late Wisconsin age found within the Whitewater River basin. This means that Des Moines lobe meltwaters did not course through this drainage basin; and therefore, the soil could not have formed in 'sandy drift.' We propose instead that at least some surficial coarse-grained deposits are eolian in origin based on the mapped distribution of the Plainfield series only on the east and southeast, or downwind, sides of the middle and lower Whitewater valley. Where eolian sand appears particularly thick, it is mapped as VTE15. Two paleochannels of low order tributaries (VPC15) cut across the backsides of terrace remnants near the tributary junctions with the Whitewater Valley. The sediment association consists of at least two meters of colluvium and local alluvium that is likely Historic in age.

The VT14 LfSA is closely related to the VT15 LfSA, usually occurring no more than about two meters lower in elevation, and often adjacent to VT15 remnants in similar landscape positions. VT14 LfSA remnants extend from the upvalley end of the middle reaches of the North Fork and Middle Fork downstream to the Whitewater Valley mouth. In the upper part of the middle reach, remnants are generally narrow, except where they are represented within older bedrock meander loops. Elsewhere in the middle reach, remnants can be larger. Here, the sediment assemblage is similar to the VT15 sediment assemblage, dominated by fine grain slackwater facies. In the lower reach, VT14 can be underlain by sand and gravel, suggesting in places that it could represent a channel facies, related to, or inset into, the VT15 LfSA.

VT8 terrace remnants are limited to just upvalley and down-valley of the shift from the bedrock meander reach to the middle reach of the North Fork. Remnants are small and occur on the outside, crossover, and inside parts of the meanders. The VT8 LfSA is the oldest of the lower suite of terraces and generally occurs adjacent to upland slopes, suggesting a significant episode of incision occurred between the higher and lower terrace suites. As a result of their valley margin position, VT8 remnants often are partially or entirely buried by small alluvial fans and colluvial slopes. The sediment assemblage is fine grained, with up to one meter of a terrace veneer facies that is Historic in age overlying a buried soil developed in older floodplain overbank sediment.

VT7 terrace remnants extend from the lowest part of the bedrock meander reach downstream through the middle reach to the lower reach. Remnants abut hillslopes rising to upland surfaces, terraces of the higher suite, and a few VT8 terrace remnants. In the bedrock meander reach, small, narrow, generally elongated remnants occur on the inside, outside and margins of crossover positions. Between about 1.0 and 1.5 m of silt loam overbank deposits overlie fine and medium sand. In the middle reach, some remnants are medium in size. A few of these remnants are backed by arcuate cuts into older surfaces indicating a meandering Whitewater River with relatively small meander radii preceded the VT7 terrace formation. Some remnants appear to be preserved proximal parts of relatively early alluvial fans. The associated sediment assemblage to a two-meter depth in the upper part of the middle reach ranges from loam to sand and gravel. In the lower middle reach, sand and gravel dominates. In the lower part of the bedrock meander reach, and upper part of the middle reach, a number of paleochannels (VPC7) are associated with larger VT7 remnants. At the transition between the two reaches, one paleochannel has a fair size relict mid-channel bar (VB7). In the lower reach, only a few small remnants are preserved due to later meandering of the Whitewater River. These few remnants are too small to have had reliably mapped soils, so the associated sediment assemblage is unknown.

Many remnants of the VT5 terrace are preserved in the bedrock meander reach of the North Fork and upper middle reach, including both the North and Middle Forks. Few small remnants are preserved down-valley. Several remnants of a tentatively correlated terrace are preserved in the upper reach of the Middle Fork. In this latter position, VT5 remnants are small to moderate in size, inset below remnants of the high suite of terraces and upland surfaces. In the latter case, colluvial slopes mantle the backsides of the remnants. Beneath these surfaces, between about 1.0 and 1.5 m of silt loam loess or floodplain overbank terrace veneer facies overlies fine and medium sand channel and bar facies. In the bedrock meandering reach, nearly all remnants occur within crossover positions in the meanders. The most common sediment assemblage consists of greater than two meters of floodplain overbank facies beneath a terrace veneer facies that is largely historic in age. Less represented is a sediment sequence of less than one meter of the same terrace veneer facies over a sandy to gravelly bar and channel facies. There are a couple of paleochannels (VPC5) in this reach that occur across and cut into VT5 remnants. In the upper middle reach, VT5 remnants are small to moderate in size and inset into VT7 and older terrace remnants. The backsides of VT5 remnants are often marked by arcuate contacts with older surfaces marking a former Whitewater River with relatively low meander wavelength and radius. VT5 remnants occur adjacent to the Holocene and Historic meander belts. In this valley position, the VT5 sediment assemblage consists predominantly of a terrace veneer facies overlying sand and gravel bar and channel deposits. In this reach, there are several paleochannels (VPC5) that meander with a relatively small radius and meander wavelength. They are filled with a thick (>2 m) increment of terrace veneer facies that has a cumulic solum in excess of one meter thick. Whether this is entirely, or only partly, Historic in age is unknown. In the lower reach, several very small remnants are preserved in lower reaches of tributary valleys only.

VT4 remnants are very few to few in numbers and small in size in the middle and lower reaches of the Whitewater Valley where they are inset slightly into VT5 and older terrace remnants. In the upper reach of the Middle Fork, moderate to small remnants are nearly continuous into the uppermost bedrock meander reach. In the upper valley, VT4 remnants occur mostly between remnants of the high terrace suite and the Holocene and Historic channel Floodplain landscape. Except for the largest remnants, VT4 preservation alternates on either side of the Floodplain landscape. The most common sediment assemblage associated with VT4 remnants consists of an increment of silty terrace veneer facies, largely of Historic age, overlying one or more buried soils developed in floodplain overbank facies, which is at least two meters thick. The four VT4 remnants just upvalley from the bedrock meander reach surround four slightly higher streamlined areas mapped as bars (VB4). Those two differentiated by NRCS soil mapping suggest one (the most irregularly shaped) has a substantial erosional component on older sediment. The other suggests the bar sediment assemblage consists of a loamy bar-top facies over bar and/or channel sand and gravel. In the uppermost part of the upper reach, in formative low order valleys, the Floodplain landscape is flanked by nearly continuous narrow remnants of VST4 in footslope positions. These are essentially strath terraces that are cut into shale bedrock showing some evidence of pedogenic alteration.

VT4 remnants within the first few bedrock meanders are small and narrow, occurring within the outside and crossover positions of the entrenched meanders. In this position, remnants are either mostly underlain by colluvium and considerably older erosion surfaces and related deposits, or were too small to have mapped terrace soils differentiated. In the middle reach, remnants are small in size with a few moderate in size. They are mapped for the most part adjacent to the Holocene or Historic Floodplain landscape and alluvial fans. Sediment assemblages range from at least two meters of silty floodplain overbank facies to a thick (possibly greater than two meters) terrace veneer facies over silty to loamy floodplain overbank facies that can have one or more buried soils. Only two remnants of the VT4 are mapped in the lower reach, and they occur as narrow slivers at the foot of the VT15 terrace.

The VT3 LfSA is represented only within the bedrock meander reach of the Middle Fork. Common remnants are relatively small to moderate in size, and narrow in form. Some remnants are clearly bar-like in form, while some show relief due to linear scour. VT3 remnants occur on the inside, outside and crossover segments of the meanders. In distribution, VT3 remnants are inset into, and occur down-valley from, VT4 remnants in the bedrock meander reach. The are bounded by the Holocene to Historic Floodplain landscape. The sediment assemblage consists of up to a meter of terrace veneer facies overlying bar and channel sand and gravel.

5.5 Valley Margin Landscape

There are three main components of the Valley Margin Landscape: alluvial fans, colluvial slopes, and periglacial valley margin features. Only a smattering of the latter was mapped to provide an example illustrative of valley margin landform variability. Alluvial fans are by far the most significant of these components in terms of both area covered and geologic potential for hosting buried cultural deposits. The fans of the larger tributaries (Cannon, Zumbro, and Whitewater rivers) exhibited sufficient evidence of multiple lobes and associated features that they were subdivided extensively. Thus, there are multiple generations of a number of alluvial fan-related landforms. Up to 15 generations of fan lobes (MAF:22; MAF1:22 through MAF15:22) are evident on the larger fans. In some cases, distal low-lying areas (MAF(D):22; MAF(D)1:22; MAF(D)3:22; MAF(D)4:22; MAF(D)5:22; MAF(D)14:22) were differentiated. In a few cases, fan generations were differentiated based on the surface upon which they were deposited (MAFV1:22; MAFV2:22; MAFV3:22). Fan lobe paleochannels (MPC:22; MPC1:22 through MPC16:22), some with associated overbank belts of sediment (MOBO1:22; MOBO2:22; MOBO5:22 through MOBO10:22; MOBO14:22), and paleomeander belts (MMB1:22 through MMB4:22; MMB6:22 through MMB8:22; MMB10:22 through MMB13:22) were often evident, associated with lobes of the same generations. On several of the larger fan lobes, crevasse splays (MCSO1:22; MCSO2:22; MCSO7:22; MCSO8:22) and crevasse splay paleochannels (MCH1:22; MCH2:22; MCH8:22) were evident. In a few locations, small basins on mostly distal parts of fans were assigned to floodplain landforms (MFWO2:22; MFWO3:22; MFXO2:22; MFXO6:22).

Two different colluvial aprons were mapped. They are distinguished by the age of the surface upon which they were deposited. The MC2:22 LfSA tends to be a continuous sediment assemblage that was deposited on the back-sides of terraces of various origins in the UMV and lower reaches of tributaries. Basal ages can pre-date the Paleoindian period. The MC1:22 LfSA is deposited on Valley Terrace and Floodplain sediment assemblages that are considered to be Holocene in age. They have a younger basal age, and therefore may not represent the entire Holocene. This type of colluvial slope is more extensive than mapped because individual examples can be too small to map.

Mostly higher in the landscape than the MC2:22 LfSA, there are additional colluvial landforms likely formed in the periglacial environment, both erosional and depositional. Their significance, if any, to archaeology is unknown, but some examples were mapped. They are far more extensive than what we were able to map, and are regarded by us to be important elements in shaping the upland hillslope landscape close to the UMV. Nivation hollows (MNH:22) are hillside depressions that form by erosion beneath snow. They may not be as important as nivation hollow ramps (MNR:22), which are ramp-like features that extend from the downslope lip of nivation hollows, downslope to higher terrace surfaces.

In a few cases, mappable hill slopes (MH:22) formed in colluvial deposits. Another rare valley margin feature is a lake (MLN:22).

5.6 Lacustrine Landscape

The lacustrine landscape is limited to three lakes (LLN:22) in the uppermost mapped reaches of the Vermillion and Cannon River valleys. They both occupy ice-block meltout basins within these two meltwater valleys.

5.7 Floodplain Landscape

The Floodplain Landscape occurs in the Mississippi River Valley, its four main tributaries that were mapped for this project, and the mouths of numerous other tributary valleys of intermediate and low order. The Floodplain Landscape is inset into the Terrace Landscape. In the absence of the Terrace Landscape, the Floodplain Landscape is adjacent and inset into undifferentiated uplands that can include stepped erosion surfaces. However, more often, the Floodplain Landscape is adjacent to, or inset into, elements of the Valley Margin Landscape. In the case of the tributary Floodplain Landscape, it can grade downstream to, or be inset into elements of the Valley Margin Landscape in the Mississippi Valley. For reaches of tributaries that flow for some distance in the Mississippi Valley before joining the Mississippi River, the tributary Floodplain Landscape can occur adjacent or inset into elements of the Mississippi River Floodplain Landscape.

5.7.1 Mississippi River Valley

The Mississippi River (FR:22) and in some cases, its tributaries (FR:22, FR:13), are directly or indirectly responsible for shaping the valley floodplain as it would have appeared prehistorically. The lock and dam system has imposed its own imprint on the valley by creating pools – essentially riverine lakes (FLR:22), changing water planes, and influencing flood magnitudes and frequency through management plans. There is abundant alluvium of post-Euroamerican settlement age throughout the flood basins, and the installation of locks and dams has undoubtedly introduced changes in the foci, and in some cases pattern, of sedimentation from pre-dam conditions as reflected by late Historic maps.

Distinct and discrete flood basins are constructed as the Mississippi River entirely or nearly crosses repeatedly from one valley wall or terrace margin to the opposing valley wall or terrace margin. Within each flood basin, there are suites of deposits directly attributable to a range of valley depositional environments. Thus, the flood basins are resolved beyond the less informative 'floodplain' rubric. In fact, polygons representing otherwise undifferentiated floodplain basins are few in number and small in size. Collectively, flood basin landscapes result from the interactions among crevasse splay, natural levee, bar, island-braid belt, alluvial fan, and tributary creek subsystems, along with the downstream and lateral migration of the Mississippi River channel. The position and geometry of the small, undifferentiated floodplain basins is determined by the distribution of deposits of the aforementioned subsystems.

The relative importance of any given valley depositional subsystem and the architecture of the resulting deposits in a flood basin are conditioned by a number of factors. The amount and style of overflow that occurred and currently occurs at the head of the each basin, essentially flowing down-valley, can be a major source of water and sediment discharge into the basin. Mega-crevasse splay systems originating at the head of a basin dominate some of the flood basins. The amount and style of lateral overbank deposition that occurred and currently occurs along the river-side margin is often dominated by a continuum of natural levee to crevasse splay overwash. However, the geometry and distribution of these deposits are sometimes conditioned by the position of earlier Mississippi River channels that are entirely or partially buried, and / or, if present, mega-crevasse splay systems emanating from the flood basin head. Short reaches of Mississippi River paleochannels that are Historic, and possibly latest prehistoric, in age, flank the river-side of a number of flood basins. These particular paleochannels are the result of the most recent shifts in river meander position. Both the distance between the river-side flood basin margin and the current Mississippi River channel, and the spatial relationship between the flood basin margin and channel orientation further influence the flood basins. Finally, the distal side of flood basins is affected by inputs of water and sediment from tributaries. Earlier increments of alluvial fans have been removed where the Mississippi River swung along a valley or terrace margin segment, only to be replaced by additional alluvial deposits with a younger basal age. Larger perennial streams with attendant landforms such as natural levees and paleochannels coursed through some flood basins, often just beyond the valley or terrace margin. Smaller tributaries coalesced in these systems before debouching into the Mississippi River, usually at the distal end of flood basins.

There is further patterning of the valley geomorphology. Below St. Paul, the Mississippi River (FR:22) has a low sinuosity meander pattern that can be superimposed on the valley-wide swings of the river. Lateral channel migration has resulted in relatively short, abandoned paleochannel reaches and chutes in various stages of atrophication. These are considered to be relatively quite young, perhaps early Historic to latest prehistoric in age. Nevertheless, the current river channel is characterized by common mid-channel islands that are actively growing and changing form. Historic maps from the late 1800's suggest the islands began as mid-channel bars. In several reaches, there are relatively small areas of linear ridge and swale morphology suggestive of an island braid to braid pattern. These areas consistently occur adjacent or very close to the active Mississippi River channel. With distance from the active channel, these landforms give way to the aforementioned more complex flood basins.

Many of the depositional environments of the flood basin landscape are represented by multiple generations. Relative age relationships are distinguished by cross-cutting relationships. Although a group of LfSAs of a particular depositional environment are related by relative age, they cannot be related to other groups of the same depositional environment in another flood basin because of the discontinuity among flood basins, or, the overall valley or terrace wall to valley or terrace wall pattern of the Mississippi River. Although contemporaneity cannot be demonstrated among flood basins, it is likely that LfSAs of a particular relative generation are similar in age to those of the same assigned relative generation, give or take a generation.

While the mapping illustrates multiple generations in the evolution of the different floodplain subsystems, these reflect only the latest patterning of the flood basins. It is likely that in the vertical dimension, the current pattern overlies one or more generations of other patterning, thus leading to a potentially complex three-dimensional sedimentary architecture. However, the patterning of one vertical generation to the next vertical generation may or may not have varying degrees of similarity to its predecessor. Informal comparison of mapped sediment assemblages to those shown on the detailed maps of 1895 show that some depositional environments remain active through time, and that some relict geomorphic features have persisted. In many areas, however, the positioning of depositional environments and their relationships to one another have shifted usually due to the shift in depositional centers of one or another depositional environment.

Some floodplain LfSAs are subdivided based on their distal position, usually relative to water and sediment source. Often this division follows abrupt lateral shifts in vegetation that are related to elevation and duration of inundation. This division is significant because lower-lying parts of these LfSAs are likely to have an overall lower geologic potential for buried prehistoric cultural deposits. This is not a firm boundary, however, as there can be extensive lateral shifts in water level of the pools. Furthermore, pool levels are somewhat higher than the original floodplain, and superimpose a stepped, planar water surface over what had naturally been a continuous, gently sloping, floodplain surface.

Based on assessment of the 1895 map series, comparisons of historic and modern aerial photographs and other map series, and interpretations of soil series profiles, almost all LfSAs of the Floodplain landscape have a mantle of 'Type O' overbank deposits. This type of overbank deposit is characterized by very weak or negligible soil development, and preservation of primary sedimentary structures. They can range from thin to greater than 2 m thick and are considered Historic in age. Thickness and distribution of 'Type O' overbank deposits is conditioned to some degree by the level and management of pools behind the locks.

Rising above the flood basins are two terrace levels that are considered Holocene in age and part of the floodplain landscape. Along with the youngest terrace that is considered pre-Holocene in age, these terraces show a downstream trend relative to one another. Progressively older terraces extend farther downstream. While this may reflect the true distribution of these surfaces, it may well be an artifact of subsequent changes in the general slope of the floodplain. These terraces may extend farther downstream, but in locations now buried by younger floodplain LfSAs.

5.7.1.1 Natural Levees

The abundance of natural levees along the Mississippi River, its paleochannels, and its tributaries where they flow in the valley reflect both the flood regime and an ample supply of sediment. Some crevasse splay channels are also flanked by low natural levees, but these are not always distinguished. Lower-lying, more distal parts of levees are often distinguished, especially where they tend to form extensive aprons. Some natural levee polygons include few to numerous small crevasse splays.

Natural Levee systems are differentiated by their relative age to one another. Progressively older natural levees of the Mississippi River tend to have a fine grain upper increment as they become more distal from the active channel. Basal levee deposits may be time-transgressive as well, particularly where they formed by the Mississippi River as it prograded into Lake Pepin upstream of Red Wing. This same process may have been in effect for other, now-filled, valley lakes that could have similarly formed behind fan deltas deposited by the Black River and other tributaries. The main natural levee LfSAs are FNLO1:22 to FNLO8:22. Related distal levee LfSAs are FNL(D)O1:22 to FNL(D)O8:22.

Natural levee systems progressively become less extensive, more discontinuous; and more likely to be preserved in a down-valley direction with greater age. FNLO6:22, FNLO7:22 and FNLO8:22 LfSAs are mapped in the southernmost flood basin where there is a complex of crevasse splays, partially filled Mississippi River paleochannels, tributary creek paleochannels, all potentially with natural levees. FNLO4:22 levees are very few in number and occur downstream of the Zumbro River mouth. Few examples flank the Vermillion River paleochannel system, and occur in the southernmost flood basin. The FNLO3:22 LfSA also occurs only downstream of the Zumbro along short reaches of Mississippi River paleochannel. There are relatively extensive remnants along a paleochannel of the Vermillion River that flows between younger paleochannels and the distal natural levee. The FNLO2:22 levee is more common than the FNLO3:22 LfSA, but it still occurs as short, discontinuous segments, preserved primarily along short Mississippi River paleochannel reaches downstream of the Vermillion River mouth. A modest number of FNLO2:22 polygons occur along the Vermillion River paleochannel and along a tributary paleochannel in the southwestern flood basin. The FNLO1:22 natural levee and associated distal FNL(D)O1:22 LfSA flanks most of the modern Mississippi River channel. It also is mapped along the extensive Vermillion River channel where it flows across mostly older catastrophic flood surfaces, as well as a tributary in the southernmost flood basin.

5.7.1.2 Crevasse Splay Systems

Crevasse splay systems occur along the modern Mississippi River, its paleochannels, and the long paleochannel of the Vermillion River in the Mississippi Valley. Substantial parts of some flood basins, particularly downstream of the Chippewa River mouth, are comprised of some of the largest individual crevasse splay systems. Some of these may in fact represent former delta systems, but some in flood basins where their course is clearly influenced by one or more preceding Mississippi River channels. Where crevasse splays are large and complex enough, their components are distinguished, including individual crevasse splay main stem and distributary channels, meander belts of substantial crevasse splays, and crevasse distributary mouth bars in the distal ends of the largest splays. Some crevasse splay systems are further subdivided by delineating their lower-lying distal positions. Lower-lying parts of splays occur in positions more distal to both the main crevasse splay channel, and the overall body of the splay. Further subdivision of the distal parts of largest splays includes those distal positions that are perennially or for the most of the year inundated with water, including crevasse distributary channels.

The main differentiator of various crevasse splay systems is their relative ages, either along river reaches that have been actively migrating, mostly during the Historic period, or in flood basins where they can be slightly older. The main crevasse splay LfSAs, from oldest to youngest are FCS06:22 to FCS01:22. Distal, lower-lying parts are identified by LfSAs FCS(D)O6:22 to FCS(D)O:22. Inundated parts of some distal splays are identified by LfSAs FCS(D)WO1:22 and FCS(D)WO3:22. Larger splay systems with differentiated components have partially backfilled relict channels, identified by LfSAs FCH1:22 to FCH7:22, and inundated relict channels, identified by LfSAs FCHW1:22 to FCHW4:22 plus FCHW7:22, distinguished by relative age of the splay system. In two instances, distal splay channels bifurcated multiple times, forming swarms of what effectively are distributary mouth bars, identified by LfSA FDSO:22. Lower-lying parts of these bars are differentiated by the FDS(D)O:22 LfSA. In one instance, the main splay channel developed a meander belt of its own, identified as the FCMO1:22 LfSA.

In general, crevasse splay systems progressively become less common with age. There are, however, very few FCS06:22, FCS05:22 and FCS04:22 splays. FCS03:22 and FCSO2:22 splays are still relatively few. The majority of the splays belong to the FCSO1:22 LfSA. Correspondingly, the distal splay LfSAs follow the same general trend, and are less frequent than their proximal LfSA neighbors. The FCSO1:22 LfSA is represented by two complexes of some size between the Vermillion and Cannon River mouths. Otherwise, there are few small splays upstream of the Whitewater River mouth. FCSO1:22 splays are far more numerous and generally larger downstream of the Whitewater River mouth. The largest two complexes occur downstream of the Root River alluvial fan. FCSO2:22 splays are most common in the lowest flood basin. A few are associated with the Vermillion River paleochannel in the Mississippi Valley. FCSO3:22 and FCSO4:22 splays are mostly associated with short Mississippi River paleochannels near the active river downstream of the Whitewater River mouth. One FCSO3:22 splay is represented along the Vermillion River paleochannel system. FCSO5:22 and FCSO6:22 LfSAs are limited to the complex southernmost flood basin in the project area.

5.7.1.3 Paleochannels

Paleochannel LfSAs include both those of the Mississippi River and tributary creeks that flowed through flood basins. Almost all paleochannels are differentiated by relative age. The relatively oldest paleochannels are located in the southernmost flood basin in the UMV project reach. LfSAs FPC10:22 to FPC5:22, along with their related inundated examples, FPCW10:22 to FPCW5:22, are limited to this flood basin. FPC10:22 is a former Mississippi River channel that is now completely buried on the upstream half of the flood basin. All examples of the FPC8:22 and FPC7:22 LfSAs, and nearly all examples of the FPC6 and FPC5 LfSAs, belong to a complex paleochannel system that originated as Mississippi River overflow at the north end of the flood basin. Subsequently, they were then heavily modified by Clear Creek and Crooked Creek, two tributaries that share a valley mouth at the head of the flood basin. The few examples of the FPC6 and FPC5:22 LfSAs not clearly related to the activity of these two creeks represent very short paleochannel reaches that are surrounded by younger surfaces such that their origin is unclear. One grouping of these LfSAs might be related to tributary creek activity, but all groupings could be related to crevasse splay systems. The FPC4:22 and FPCW4:22 LfSAs consist of relatively few examples of short, discontinuous Mississippi River paleochannel reaches downstream of the Zumbro River mouth. There are a few tributary paleochannel remnants in the southernmost flood basin, and a rare tributary example elsewhere. A similar distribution holds for the FPC3:22 and FPCW3:22 LfSAs. There are slightly more examples of the FPC2:22 LfSA along the Mississippi River downstream from the Chippewa River Valley mouth, and in the southernmost flood basin, but only a few examples related to tributary creeks elsewhere, and the Vermillion River in the Mississippi Valley. There is a far greater number of examples of the FPC1:22 and FPCW1:22 LfSAs. Almost all are Mississippi River paleochannel segments that as a group extend northward to above the Vermillion River Valley mouth. Short reaches of tributary FPC1:22 LfSAs occur locally.

Undifferentiated paleochannels (FPC:22) in the Mississippi Valley are very few in number, and include only tributary paleochannels and no Mississippi River paleochannels. Included are paleochannel reaches of the Black River, Rollingstone Creek and a low order tributary. These examples are mapped because they have not been completely buried by subsequent alluvial fan or fan delta activity, or deposition from other floodplain environments.

5.7.1.4 Island-Braided Floodplain

Along the length of the project reach, there are relatively small areas adjacent to the active Mississippi River and within some flood basins that exhibit an island-braid pattern that are distinguished as the FIBO:22 LfSA. From their position, in general they appear to range from slightly older than, to coeval with, the mid-channel and lateral bars that mark the project reach of the Mississippi River (see Section 5.7.1.5 below). Most are mantled to one degree or another with an overbank veneer, often in the form of natural levees. Inundated parts of the undifferentiated island-braided floodplain are distinguished as the FIBWO:22 LfSA. In one location in the upper part of the project reach, sedimentological conditions have allowed less than a meter of peat or organic muck to accumulate in a local basin resulting in the distinction of the FIBOMA<:22 LfSA. Where subdivided into their constituent elements, the 'islands' (FIBIO:22) are elongated, low ridges, and consist of greater than two meters of very fine and fine sand. Braid channels (FIBBO:22) are similarly elongated troughs between the ridges. Braid channels are complicated by subsequent infilling to various stages by mouth-blocking bars and general inflow, the degree of which often varies along their lengths. Lengths of braid channels that inundated most or all of the time are further distinguished as the FIBBWO:22 LfSA. Channel fill is dominated by very fine and fine sand that is greater than two meters thick, but interstratified fine grain beds are likely to be common.

5.7.1.5 Bars

The bar environment is associated almost entirely with the modern Mississippi River channel. They are prominent features on early maps of the valley, with some maintaining their position and, in some cases form, through more than the last century. Bars with a ubiquitous overbank veneer (FBO:22) occur along the length of the project reach of the UMV, except within Lake Pepin and upstream of the southernmost part of South St. Paul. Generally below Lake Pepin, a distal, low-lying, bar facies (FB(D)O:22) is often differentiated. Local basins on distal bars that might be exposed only at very low water are further distinguished as the FB(D)WO:22 LfSA. Most bar examples are of the mid-channel variety, with a fewer number of mapped lateral bars. The size of individual bars undoubtedly can vary greatly with the height of pools and floods. Bars are even more extensive than mapped, but a number of them are now mantled to various degrees by natural levee LfSAs that contribute to their stabilization. Active bars also occur far less frequently in some secondary side channels, and some particularly active flood basins. Bars and their overlying mantle consist primarily of very fine and fine sand that is greater than two meters thick.

Included in the FBO:22 LfSA are a few examples of large relict mid-channel bars that are morphologically recognizable in lower flood basins despite subsequent modification. They mark former courses of the Mississippi River, and are probably more in number than are mapped, although some are undoubtedly buried completely by younger overbank deposits. One particularly large example has been assigned to the fifth discernable generation (FBO5:22) of deposits in the southernmost flood basin; and, it has a related distal facies (FB(D)O5:22) LfSA. These relict bars are dominated by very fine and fine sand that is greater than two meters thick, but the overlying veneer can be finer grained.

5.7.1.6 Lake Pepin

Even before the establishment of the lock and dam system, Lake Pepin formed upstream of the fan delta of the Chippewa River, and functioned as a riverine lake (FRL:22). Where the Mississippi River now progrades into Lake Pepin, it branches into two distributary channels. Each channel is flanked by relatively young natural levees (FNLO1:22) that collectively represent the leading edge of a delta confined by terraces and valley walls. Within Lake Pepin, tributaries of all sizes have deposited fan deltas (FFDO:22) or alluvial fans (MAF:22). Where sediment yield has been great enough, and lake currents favorable, spits (FSPO:22) have formed.

As the Mississippi River has progressively extended into Lake Pepin in the project reach since at least the late middle Holocene, it can be expected that in the past, alluvial fans and other landforms marginal to Lake Pepin, up-valley of the current extent of the lake, could have been altered by lacustrine processes.

5.7.1.7 Floodplain Lakes

Deposition of the various generations of the crevasse splay and natural levee LfSAs, and to a lesser extent the island-braided, bar and alluvial fan LfSAs have led to the development of local basins within the distinct flood basins along the project reach. Local basins almost invariably support backwater lakes (FLN:22) that are either perennial or intermittent. The form of these basins is dictated by the form and source direction of the bounding deposits. Tributary creeks instead of, or in addition to flooding by the Mississippi River, feed some of the local basins. Some local basins closer to the valley margin and tributary valley mouths may be augmented by groundwater recharge. Depending on their position relative to sediment sources, the LfSA can range from fine grain to fine sand that is greater than two meters thick.

5.7.2 Tributary Valleys

Tributary valleys to the Mississippi River generally share a common suite of landforms, despite some differences in the size of their Holocene floodplains and antecedent history relative to contributions of glacial outwash. In part, this reflects several factors common to all of the west-side tributaries between the St. Croix end moraine to the north and the Minnesota – Iowa state line. All valleys are set within an eroded bedrock terrain that exerts some influence on their form, although for the Vermillion Valley, this effect is minimal. They similarly responded by incision and headward erosion to relatively abrupt downcutting events in the Mississippi Valley during the Late Wisconsin, and earliest Holocene, setting the stage for establishment of that part of the valley active during the Holocene. Also, they responded similarly to a changing climate at the end of the Late Wisconsin, and particularly from the middle to the late Holocene. Finally, the valleys responded similarly to changes in Historic land use with Euroamerican settlement and development. Despite the common landform suite, the extent, distribution, and some characteristics of LfSAs can differ within and among the main tributary valleys and their major contributing branches.

Most main tributary valleys have an upper reach characterized by a relatively low stream and valley gradients. In those valleys fed by glacial outwash, this reach often includes stagnant basins in former outwash channels. A generally narrower reach, with a steeper stream and valley gradient, occurs down-valley, with evidence of headward erosion into the low gradient reach. This reach, when present, leads downstream into a relatively steep reach of incised bedrock meanders. In the Zumbro River valley, this reach is more complex, with at least one substantial basin within the bedrock meandering reach. There is marked reduction in stream and valley gradient at the end of the bedrock meandering reach. Although evidence of bedrock valley meanders persists into this reach, it appears the reduction in gradient is largely due to sedimentation within the down-valley reach.

Vermillion River Valley. The Vermillion Valley is most unlike the other valleys, yet still has a similar, if somewhat smaller, suite of LfSAs. In the Vermillion Valley, the Floodplain Landscape is quite limited in extent, especially when compared to the size of the valley. The response in the Vermillion Valley to incision in the Mississippi Valley was limited, and terraces that are pre-Holocene in age dominate the valley. The limited response may point to a limited discharge of the Vermillion River at the time of Mississippi Valley incision. The Vermillion River is an underfit stream inset into the broad Vermillion Outwash Plain. The river follows the course of what was one of the larger outwash braids on the VOP. The Vermillion heads in a wetland occupying one of a number of collapsed tunnel valleys emanating from the undifferentiated Des Moines Lobe to the west.

In its upper reach the Vermillion River is joined by a number of low order tributaries that either initiate on the OT15:22 outwash terrace, flowing on former braid channels, or in the adjacent stagnant ice landscapes of the Des Moines Lobe (to the west) and St. Croix end moraine (to the north); the older OT16:22 outwash plain (to the north); and, bedrock-cored uplands (to the south). These low order tributaries occupy former braid channels as they cross the OT15:22 terrace. In the middle reach of the Vermillion Valley, two narrow but distinct meander belts, one perhaps inset slightly into the other, are evident. The middle reach is separated from the lower reach by a 2.5 km-long stretch along which the Holocene valley gradient is noticeably steeper. In this stretch, the Holocene valley constricts considerably, and the sinuosity decreases noticeably in the lower third of the transition, just above the mouth of the unnamed drainageway in Rich Valley.

The gradient decreases while sinuosity increases after exiting the transition from the middle to the lower valley reach. In the lower valley reach, the Vermillion River is inset into a series of younger terraces of both its own valley and the UMV. At about the Highway 61 bridge across the Vermillion River, the gradient again increases, sinuosity decreases, and the river descends to the approximate level of the Mississippi Valley floodplain.

The Vermillion River differs substantially from the other three main tributaries in that upon entering the UMV proper, it flows for about another 26.5 km before joining the master stream. Unlike the other three rivers, the Vermillion River has not deposited a distinct alluvial fan, but rather it meanders through a flood basin that could constitute a young version of a fan, although with a very low slope. As the Vermillion River enters the Holocene Mississippi Valley, it turns to meander eastward between a streamlined terrace form to the north, and a relict alluvial fan at the mouth of Sand Coulee to the south. The Vermillion then flows in a more or less straight pattern, with an occasional meander of small radius, southeastward, more or less at or just beyond the foot of a suite of Mississippi River terraces. It continues its course southeastward as it enters a catastrophic flood marginal channel (flood chute) within Richard J. Dorer Memorial Hardwood State Forest where, undoubtedly influenced by this straight channel, the Vermillion has an extremely low sinuosity. Along this reach, the Vermillion River is locally deflected by small alluvial fans deposited by west-side tributaries. Upon approaching the southern tip of Prairie Island, which is a catastrophic flood bar, the Vermillion River, now identified as Vermillion Slough on published maps, is deflected toward the Mississippi River by the alluvial fan of the Cannon River, the river to which it eventually joins just before entering the Mississippi channel.

At one time in the recent past, at least part of the Vermillion River flow angled northward over a distance of about 2.5 km to join the Mississippi River, a distance less than a tenth of its current course in the UMV. Before it took this course, after angling north, the Vermillion River rounded the nose of the first streamlined catastrophic flood bar to flow southeastward, but on the northeast side of the bar. Although the Mississippi River flood basin entered by the Vermillion River is dominated by extensive crevasse splays, there are gaps in the splays that reveal multiple paleochannels that probably represent former courses of the Vermillion River. Similarly, closer to the modern course of the Vermillion River down-valley and through the marginal channel, there are additional younger paleochannels and related LfSAs.

Cannon River Valley. Similar to the Vermillion Valley, morphology of the upper reach of the Cannon River and the narrowness of the floodplain in which it flows exhibits substantial influence of glacial meltwater flows. In this upper reach above Lake Byllesby, the Holocene floodplain occupies the relict thalweg of a deglacial sluiceway. Other outwash channel threads support lowest tributary reaches and wetlands. The Holocene floodplain is mostly narrow, and with few exceptions exhibits a relatively low sinuosity. The upper valley reach ends where the Cannon River enters a broad basin partly filled with Glaciofluvial LfSAs, and flows into Lake Byllesby. Arcuate margins of the reservoir suggest the Cannon River sinuosity increased upon entering this basin valley reach, and the floodplain widened. The dam impounding Lake Byllesby is located at a constriction of the Holocene valley between outwash terraces. Downstream of this dam, the Cannon River flows through a transitional reach marked by an increased gradient and decreased sinuosity that reflects headward erosion into the basin in the vicinity of the town of Cannon Falls. This transitional reach leads into the middle valley reach characterized by bedrock valley meanders, a gradually widening of the floodplain down-valley, and a moderately meandering Cannon River. The lower reach is marked by a markedly lower gradient, further floodplain widening, a greater sinuosity, and multiple paleochannels that essentially mark the head of the Cannon River alluvial fan. The Cannon fan exhibits multiple lobes, with the Cannon River at times in the past flowing southeastward upon entering the UMV.

At some point in the past, pre-dating all or most of the mapped fan lobes, the Cannon River would have entered directly into Lake Pepin.

Zumbro River Valley. The North Fork Zumbro River (NFZR) heads in an elongated basin partially filled with outwash from the Des Moines Lobe. The Holocene river gradient is low and wetlands are common, including within the undifferentiated meander belt. The middle valley reach of the NFZR erodes headward into this basin. In the middle valley reach, an undifferentiated, relatively narrow, meander belt dominates the Holocene floodplain. The meander belt occupies a narrow bedrock valley that gradually widens and meanders with a relatively low valley sinuosity. Eventually within this reach the NFZR is resolved as are the floodplain LfSAs that constitute the meander belt. About 3.5 km down-valley of the community of Forest Mills, the sinuosity of the bedrock valley increases greatly. This change is rapidly followed by a marked increase in gradient in the Holocene floodplain another 4.5 km down-valley. This transition is effectively a valley knick point, perhaps correlative with the change in gradient near Cannon Falls in the Cannon Valley. These changes mark the beginning of the lower valley reach of the NFZR which is dominated by more pronounced point bar morphology. Below the knick point, the valley is slightly steeper than above. It is within this lower valley reach that the NFZR joins the northward-flowing Zumbro River in a short reach where the NFZR exhibits an increased sinuosity. The same bedrock valley meandering reach continues down-valley below the confluence, although it is by name occupied by the Zumbro River.

In the straight, uppermost, mapped valley reach of the Middle Fork Zumbro River (MFZR), the Holocene meander belt is moderately wide, and point bars are important features. A few kilometers to the east, the bedrock valley narrows and exhibits a relatively high sinuosity. The meander belt narrows, the gradient steepens slightly, and point bars remain important features. In this middle valley reach, the valley widens to about the town of Pine Island, bedrock valley meanders become less pronounced, and the Holocene meander belt broadens, exhibiting a greater area of floodplain LfSAs. Below Pine Island, both valley and Holocene floodplain narrow abruptly, then again widen down-valley, with some relatively low sinuosity bedrock valley meandering, to where the MFZR enters Shady Lake near Oronoco. There is a constriction in the bedrock valley at the dam impounding Shady Lake. From this constriction downstream, there is a modest steepening of the gradient leading into the high sinuosity bedrock valley reach where Holocene bar complexes are well developed. This bedrock valley meandering reach continues downstream beyond the mouth of the MFZR. Even though there are a few straighter reaches in the bedrock valley of the Zumbro River below the confluence of the MFZR and South Fork Zumbro River (SFZR), this valley reach appears essentially the same as that downstream of the mouth of the NFZR.

The uppermost mapped reach of the South Fork Zumbro River (SFZR) and the narrow SFZR meander belt exhibit relatively low gradients. In the vicinity of Rock Dell, the river enters a meandering bedrock valley reach with only a slight overall increase in width of the Holocene valley. This middle valley reach extends to about the mouth of Hadley Valley, several kilometers north of Rochester. The city of Rochester, however, occupies a basin partially filled with coarse-grained alluvium that interrupts the morphology and gradient of the middle valley reach. Upvalley from Rochester, the middle valley reach includes several prominent abandoned valley meanders, including rock cored paleomeanders. Through the middle reach, the valley overall widens, but the Holocene floodplain remains within a fairly consistent range of widths. The SFZR Holocene valley more or less maintains this width range as it flows through the Rochester basin. A little downstream of Hadley Valley, the Holocene-aged floodplain narrows as the SFZR enters a narrow meandering bedrock valley reach of high sinuosity, yet with distinctly smaller radii than seen in the middle valley reach. The gradient increases slightly entering the reach. The lower meandering valley reach corresponds with the lower bedrock valley reach of both the MFZR and NFZR, as well as the Zumbro River immediately down stream of the NFZR mouth.

The Zumbro River continues down-valley in this narrow both valley and floodplain reach to a few kilometers upvalley of Millville. Here, the valley sinuosity decreases markedly, and then increases down-valley as the bedrock valley and floodplain gradually widen. In this middle reach down-valley of Millville, bedrock valley meanders exhibit a high sinuosity, but with a much larger radius than the upper bedrock valley reach of the Zumbro River. The Zumbro River and Holocene paleochannels reflect a high sinuosity Holocene-aged Zumbro River in this reach. The lower valley reach is marked by a straightening and further widening of the Holocene-aged floodplain, with numerous paleochannels and a decrease in gradient.

The Zumbro River currently is canalized eastward across its alluvial fan, and through a gap in a long catastrophic flood bar, where it then meanders southeastward a short distance to the Mississippi River. The Zumbro River alluvial fan is substantial in size, in part reflecting that it is deposited on a catastrophic flood marginal channel or chute on the west side of the flood bar. Many former channel courses mark relict fan lobes, with the river having at times flowed northward, or southward, around the flood bar before joining the Mississippi River.

Whitewater River. Uppermost mapped valley reaches of the North (NFWR) and Middle (MFWR) Forks of the Whitewater are characterized by a low gradient, poorly drained, and relatively low sinuosity floodplain. In both forks, there is a rapid transition to a floodplain of considerably steeper gradient and better drained soils in a meandering bedrock valley reach with relatively high sinuosity and small radii. Floodplains remain narrow and point bars can be prominent features. Both forks transition rapidly again into the middle valley reach where remnants of bedrock valley meanders suggest an increase in the radius of curvature down-valley. The two forks merge to form the Whitewater River within this middle valley reach. Floodplain gradients decrease markedly at the heads of the middle reach and progressively the floodplain widens down-valley. There is a gradual transition into the lowest valley reach where the floodplain widens further, is characterized by multiple paleochannels and paleo-meander belts, and has a very low gradient. The bedrock valley wall is still marked by several remnants of former bedrock valley meanders. Essentially, the three lowest reaches in the Whitewater River Valley and its contributing valley forks in general correspond with the three lowest reaches of the Zumbro River Valley.

Part of the lowest reach of the Whitewater Valley floodplain is probably more accurately described as part of the Whitewater alluvial fan or even more accurately a fan delta. Part of the fan or fan delta is undoubtedly beneath one of the pools impounded behind a dam. However, it is likely that the Mississippi River swung toward this side of the valley relatively late in the Holocene, eroding any earlier manifestations of a Whitewater alluvial fan.

Lowest Reaches of Other Tributaries. There are many intermediate and low, and a few additional higher order tributaries in the project area, the mouths of which were mapped. Generally, the same patterns observed in the lowest reach of the Zumbro, Whitewater, and, to a fair degree, the Cannon valleys holds for tributaries large enough to have developed a meander or channel belt.

5.7.2.1 Floodplain Landform Sediment Assemblages

The following descriptions refer to the four large tributaries, but the same assortment of LfSAs occur within the mouths and lowest reaches of smaller tributary valleys as in the corresponding valley position within the higher order valleys.

Rivers (FR:22) are mapped where they are wide enough to be resolved reasonably at the scale of mapping. Similarly, active bars (FBO:22) , usually point bars, are mapped when they are large enough. Examples of the FBO:22 LfSA amount to: only two in the Cannon River Valley mapped just downstream of Cannon Falls (the upper part of the middle valley reach); many in the Zumbro River Valley in nearly every valley reach where the FR:22 LfSA was distinguished; and, many in the Whitewater River in the meandering bedrock valley reaches and continuous through all but the lowest few kilometers of the middle valley reach. There are a limited number of mostly small reservoirs (FLR:22) impounded behind dams in the Cannon and Zumbro systems. In the Cannon Valley, three reservoirs (FLR:22) occur in the upper reach, with one just above the town of Cannon Falls, occupied by Byllesby Lake. At the head of this lake, the upper reach of the Cannon River has deposited a small delta (FDEO:22). The other two reservoirs (FLR:22) are farther upvalley, with the highest occupying a large ice block meltout depression. A reservoir (FLR:22, Zumbro Lake) was created along the narrow north-south part of the upper reach of the Zumbro River. Smaller reservoirs (FLR:22) occur on the MFZR (Shady Lake at Oronoco) and SFZR (Silver Lake at Rochester, and an unnamed very small reservoir immediately upstream of the Rochester city boundary).

Where the rivers are not wide enough to map in some of the uppermost valley reaches, they are part of an undifferentiated meander belt (FMB:22). Usually, the FMB:22 LfSA in these valley positions is poorly to very poorly drained, with some marshy conditions (FMBMA>>:22) existing locally.

The FFWO:22 floodplain LfSA occurs adjacent to rivers (FR) and bars (FBO) in nearly all valley reaches. It primarily is mapped on the youngest parts of point bars on the inside of meanders. This LfSA generally has poorly drained soils, particularly in upper and lower valley reaches. In the Vermillion River Valley, the FFWO LfSA occurs as a very narrow belt from the very downstream end of the middle reach, through the transition, and into the upper part of the lower reach. In the Zumbro River Valley, the FFWO:22 LfSA occurs as small discontinuous segments that only become notably larger in the lower valley reach. In contrast, in the lower valley reach of the Whitewater River Valley the FFWO:22 LfSA is quite discontinuous, and the LfSA becomes sparse in the lowest few kilometers. Higher in the valley, the FFWO:22 LfSA is nearly continuous in meandering valley reaches and other high sinuosity reaches.

On its margin closer to the FR:22 LfSA, the FFXO:22 LfSA is adjacent to the FFWO:22, FBO:22 and FR:22 LfSAs, usually at a slightly higher elevation, where the river has migrated laterally and down-valley. What little floodplain is present in the lower valley reach of the Vermillion Valley is mapped as the FFXO:22 LfSA. It is narrow to nonexistent here, reflecting the steeper, incised character of this valley reach. In the Cannon Valley, the FFXO:22 LfSA is located in the upper valley reach above Lake Byllesby, In the middle and particularly lower Cannon Valley reaches, this floodplain type in the same geomorphic position is marked by a buried soil (FFXOB:22) beneath the overbank veneer. The FFXOB:22 LfSA is more continuous in the lower valley reach. An undifferentiated polygon in a more remote cutoff meander sequence at Cannon Falls is assigned to the FFX LfSA.

In the Whitewater and Zumbro Valleys, the FFXO:22, FFXOB:22 and undifferentiated FFX:22 LfSAs are usually either associated with the insides of meander bends, or occur as distinct floodplain segments with some degree of internal variability. In the Zumbro Valley, the FFXO:22 LfSA is common in all but the NFZR where it is almost unmapped, in part due to the undifferentiation of much of its meander belt, and the SFZR where it is nearly continuous through most of the middle reach and parts of the upper reach. The FFXOB:22 LfSA, reflecting preservation of a buried soil and/or cumulic soil beneath a 'Type O' sediment veneer, is nearly continuous in the lower middle to lower valley reach of the ZR, with a scattering in the middle valley reach of the SFZR. In the meandering bedrock valley reaches of all forks of the ZR, where 'Type O' overbank sediment and associated buried soils are apparently less common, the FFX:22 LfSA is common to abundant. In the Whitewater Valley, the FFXO:22 LfSA is almost continuous in all valley reaches except the uppermost reaches of the two forks where it is absent to sparsely represented. In these upper reaches, the FFXOB:22 LfSA is almost continuous. The FFXOB:22 LfSA is also common in the middle valley reach to the upper part of the lower valley reach.

In the Whitewater Valley, reaches of paleomeander belts (FMB2:22), representing undifferentiated point bar, bar and paleochannels, cut across the distal parts of a few FFXO:22 and FFXOB:22 LfSA segments in the middle reach and uppermost part of the lower valley reach in the Whitewater Valley. Two such paleomeander belts occur in the Zumbro, one in the lower part of the middle reach of the Zumbro River Valley, and one, amongst mostly terrace LfSAs, in the middle reach of the MFZR

Distinct paleochannels (FPC2:22) beyond the limits of these paleomeander belts, but associated with the FFXO:22 and FFXOB:22 LfSAs are sparse in the lower part of the middle valley reach of the Whitewater Valley. In the lower valley reach, there is a long extent of the FPC2:22 paleochannel along the northwest side of the valley. It is flanked by very low natural levees (FNLO2:22) or overwash. Some reaches of this natural levee at the transition from the middle to lower valley reaches possibly have buried soils (FNLOB2:22). In the Zumbro system, paleochannels (FPC2:22) are common in the upper meandering bedrock valley (middle) reach of the SFZR and lower meandering bedrock valley (middle) reach of the Zumbro Valley. In one location in the transition from middle to lower valley reach of the Zumbro Valley, a length of natural levee FNLO2:22) is associated with one of the paleochannels (FPC2:22).

The FFYO:22, FFYOB:22 and FFY:22 LfSAs occur in floodplain settings farther removed from rivers than the FFX LfSA counterparts, although none of the FFY-type LfSAs are represented in the Vermillion River Valley. They occur at or toward the outer margins of the Holocene-aged floodplain and meander belts, adjacent to FFX-type and younger floodplain LfSAs. In the Cannon River Valley, there are few occurrences of the FFYO:22 LfSA in the upper valley reach.

The FFYO LfSA is sparse to common in nearly all reaches of the Zumbro River's main valley and its three main forks. This LfSA is, however, noticeably lacking in the uppermost reaches of the forks, and in most cases where the bedrock valley is at its narrowest, and in the lowest part of the Zumbro River Valley. At the head of the meandering bedrock valley (middle) reach of the SFZR, there are a few floodplain segments of the FFYO<:22 LfSA where the sediment assemblage is less than a meter thick. Also in the Zumbro Valley, the FFYOB:22 LfSA is common in the upper-middle reach of the SFZR, the narrow (lower) meandering bedrock valley (middle) reach, and the lower valley reach. The FFY:22 LfSA is common in the upper valley reach of the Middle and South forks, with a sparse scatter of FFY:22 segments along the middle and lower valley reaches of the NFZR.

There are few paleochannels (FPC3:22) associated with the FFYO:22 and FFYOB:22 LfSAs in the lowest part of the meandering bedrock valley reach of the Zumbro River Valley, along with fewer segments of associated natural levee (FNLO3:22 and FNLOB3:22). One paleochannel (FPC3:22) example occurs in the lower valley reach, and three examples are dispersed along the middle valley reach of the SFZR on either side of the Rochester basin.

The FFYO:22 LfSA is abundant, with few exceptions, throughout the floodplains of the Whitewater River and its contributing forks. Exceptions include the upper valley reaches of the South, and most of the North forks where it is absent, the middle valley reach where it is common, and the lower valley reach where it is sparse. Buried soils in the FFYOB:22 LfSA are abundant in the upper valley reaches of both forks, and in the lower part of the middle valley reach. The FFY:22 LfSA is absent to nearly absent in the upper valley and bedrock valley reaches; common in the two forks at the transition from bedrock valley to middle valley reaches; and absent down-valley from this transition. There is one large bar (FB:22) that rises above an FFY:22 floodplain in the transition. The FFY:22 LfSA is represented in few tributaries to the upper valley, and in the lowest reaches of few tributaries where they cut through terraces in the middle and lower valley reaches.

In the upper half of that part of the middle reach of the Whitewater River Valley, below the fork juncture, a few short paleo-meander belt (FMB3:22) segments are associated with the FFYO:22 and FFYOB:22 LfSAs. In the same part of the middle valley reach, and extending into the lower reach, are segments of distinct paleochannels (FPC3:22, FPC4:22), also associated with the FFYO:22 and FFYOB:22 LfSAs.

The FFZO:22 and FFZOB:22 LfSAs are very sparse in number and limited to the middle reach of the Whitewater River valley downstream of the junction of the forks. These floodplain segments occur at the outer margins of the Holocene-aged floodplain and meander belts, adjacent to FFY-type and younger floodplain LfSAs. There is one example of a paleochannel (FPC4:22) associated with the FFZOB:22 LfSA.

Mapping extended into some of the lowest reaches of low order tributary valleys to the four main tributaries, the lowest kilometer or so of other UMV tributaries, as well as the UMV itself. Lower reaches of low order tributaries that lack a floodplain and exhibit a 'V'-shaped valley are assigned to the FV:22 LfSA. They occur in many low-order intermittent to perennial tributaries of the four main UMV tributaries, particularly those with steeper valley walls and where the gradient is relatively steep, as well as along even steeper low order valleys that drain directly to the UMV. The FV:22 LfSA was not mapped in tributaries to the Vermillion and Cannon Valleys, although the latter has some steep 'V'-shaped tributaries, particularly along its lowest reach, and there are many examples along the UMV that were not mapped. Mapped low order tributaries that exhibit narrow and/or discontinuous floodplains are assigned to the undifferentiated floodplain (FF:22) LfSA. In the four major tributaries, the FF:22 LfSA is very sparse in the lowest reach of all but the Vermillion River Valley. Numerous FF:22 segments are mapped in other UMV tributaries.

In the upper reaches of the SFZR and both forks of the Whitewater River valley, where not deeply incised, low order tributary valleys are distinguished as having an overbank veneer of 'Type O' overbank deposits (FFO:22) along the valley axis consisting mostly of redeposited loess of undetermined thickness. The FF2:22 LfSA is mapped in low order tributary valleys, mostly with intermittent streams, that exhibit relatively broad floodplains that are not incised. The valleys mapped with the FF2:22 LfSA likely have a loess or loess-derived fill, with a relict floodplain. They are mapped in tributaries to the upper and middle reaches of the forks of the Zumbro and Whitewater River valleys, as well as some other tributaries to the UMV. Their frequency and distribution is greater than the mapping might suggest.

A number of tributaries of low and intermediate order to the four major UMV tributaries, to other lower order tributaries, and to the UMV itself, exhibit active meander belts (FMB:22), particularly where they enter the next larger valley. In this position, tributaries cut across or are incised into terraces and various floodplain LfSAs, often following former chutes, depressions and paleochannels of the larger stream. In only several locations are multiple tributary channel belts (FMB1:22; FMB2:22; FMB3:22) distinguished by generation.

6 Sedimentology, Stratigraphy and Ages of Select Areas of the Upper Mississippi Valley

The UMV project area has such a wide range of landscapes, landforms and depositional environments with a large array of geological and geoarchaeological unknowns. Only a few of these unknowns could be addressed in the field because this project was essentially a mapping project. We therefore chose to focus the limited coring program on two major aspects of the evolution of the UMV in the project area; and these two aspects are further described in next two paragraphs.

One aspect is evaluating the age of the Rosemount Outwash Plain (ROP; OT20:22) and the younger Vermillion Outwash Plain (VOP; OT15:22) in the Vermillion River Valley. Related to this is the potential origin and age of some flood-modified landforms in the broad mouth area of the Vermillion Valley (Figure 2). The ROP and VOP are some of the earliest terraces in the area, and the most extensively preserved of the earliest terraces. Yet virtually nothing is known about their ages. The terraces and their ages have a significant bearing on subsequent Late-Glacial and Holocene-aged landscape evolution because these outwash plains formed near what at that time was the head of the UMV. They extended downstream, forming the landscape that subsequent events have altered. For example, the ROP, VOP, and some higher landforms at the downstream end of the broad Vermillion Valley mouth clearly were altered by prior and subsequent floods of the Mississippi River and at least one precursor that pre-dates the modern bedrock Mississippi Valley. Thus, these outwash surfaces provide a firm 'floor' to any archaeology in the project area. This focus was addressed at Areas 1, 2 and 3 which cover the proximal outwash facies of the terrace LfSAs, eolian modification to terrace surfaces, and the slackwater facies of the terrace LfSAs in the lowest reaches of tributaries.

The second main focus of coring and dating was to obtain data on the age of the last catastrophic flood(s) to course through the UMV project reach to compliment what is believed to be geomorphic evidence of this flood(s). The flood(s) is interpreted to have emanated from the Lake Superior basin through the St. Croix River Valley (Hajic and Hudak 2005), and is younger and of lesser magnitude than those that discharged through the southern outlet of Lake Agassiz down the Minnesota River Valley. This focus was addressed in Areas 4 and 5 by cores through and below alluvial fans deposited on what are expected to be some of the highest surfaces modified by this flood(s).

6.1 Area 1: Stratigraphy, Sedimentology and Age of the Vermillion Valley Glaciofluvial LfSAs.

Ten cores were taken in the outwash Vermillion Valley in Dakota County (Figure 2). Four cores (10DK07-10) were taken on related surfaces interpreted to have been modified by flood events, with the youngest flood event potentially as young as very early Holocene in age, and the earliest being of catastrophic magnitude. One of these cores, 10DK-09, was taken on the summit of an erosional residual (CER<20:22 LfSA). Two cores, 10DK-08 and 10DK-10, were taken on a flood-modified outwash surface (OTF16:22 LfSA) that rises above the VOP (OT15:22 LfSA). Core 10DK-07 was taken near the head of a shallow, flood-modified chute (OTF15:22) that accords with the OT15:22 LfSA. One core (10DK-01) sampled the undulating floor of Rich Valley, a surface that grades down-valley to the VOP. Logs in the Dakota County Well Index augment this core for construction of a general cross-section across Rich Valley. Four cores (10DK02-05) were taken on the VOP in different reaches of the valley, with core 10DK-05 taken on a braid belt of a tributary where it flowed over the VOP. Finally, core 10DK-06 was taken on the medial part of the linear eolian dune field that flanks the eastern, downwind side, of Sand Coulee to estimate the timing of dune formation on the flood-modified terrace surface upon which they were deposited.

In the broad mouth of the Vermillion River Valley, there is some geomorphic variability in the ROP and VOP, including higher streamlined and scoured geomorphic surfaces. The Vermillion Valley at its mouth is flanked by hills that form the northern edge of the dissected bedrock terrain that lies between the Des Moines lobe till to the west and the Mississippi Valley to the east (Figure 2). The Platteville Group and St. Peter Sandstone bedrock are very close to, and actually comprise, parts of the uplands (Mossler 1990a). This upland belt is marked by Late Wisconsin and likely older erosion surfaces, with small remnants of weathered pre-Wisconsin glacial drift referred to as the Hampton Moraine (Hobbs et al. 1990). Remnants of the ROP (OT20:22) are preserved along the foot of the uplands, mostly to the west, and include much of the drainage basin of Sand Coulee, a northward trending dry creek valley incised into outwash plain surfaces. An erosional scarp that arcs from the northwest to the east-southeast truncates the ROP and dissected uplands. Abutting the scarp to the north is an east-west belt of hummocky terrain that is interpreted as a belt of either coalesced alluvial fans or debris flow fans (MAFV). The fans exhibit somewhat younger distributary channel patterns.

The oldest surfaces that are of interest protrude above the level of the VOP on the north side of the Vermillion Valley mouth. They consist of bedrock-cored and outwash terrace surfaces at, near and slightly above the level of the ROP. The highest of these surfaces clearly have been scoured by catastrophic flooding with a primarily north-south orientation. Higher landforms include erosional residuals, flood-scoured strath terraces and pockets of pebble and cobble gravel that suggest a catastrophic flood flow from the north. Such a flow may well have cut the arcuate erosional scarp along the south side of the Vermillion valley. The highest surfaces are eroded such that there are several gaps through which flood flow was focused. Between higher surfaces to the north and south, the Sand Coulee is inset into the VOP (OT15:22 LfSA), but immediately surrounding surfaces (OTF16:22, OTF15:22, OTF14:22) have been scoured, with some areas leading away from the gaps shaped into shallow flood scour channels. Flooding that caused the scour would have been younger than that which formed the erosional residuals. It may or may not have been of a lesser magnitude than the earlier flood. Possible candidates are the catastrophic flooding that cut the Minnesota River Valley (Hudak and Hajic 2005); or the lesser but still significant flooding that cut the St. Croix River Valley (Hajic and Hudak 2005).

Core 10DK-09 indicated that the sampled erosional residual has a sandstone bedrock core at a depth of about 1.5 m (Figure 3). About 0.3 meters of coarse grain sediment, interpreted as fluvial deposits, is overlain by about 1.2 m of silt loam that is interpreted as waning flood deposits or a thin increment of loess. Coarse grain sediment consists of brown (oxidized), leached, crudely bedded medium sand and loamy sand. Silt loam is dark brown to strong brown (oxidized) and leached. Pedogenically, multiple black loam plow horizons truncate the C-horizon that is developed in silt loam.

In Core 10DK-08, sands interpreted as fluvial deposits are overlain by variable loam to fine-grained deposits, which are interpreted as alluvial and colluvial deposits. Brown (oxidized), non-effervescent, thin beds of sand that fine upward from coarse sand to brown fine and medium sand overlie bedrock. This sequence is capped by two couplets of strong brown fine to medium sand overlain by a thin bed of sandy clay loam diamicton that includes rounded clasts of exotic pebble gravel. The diamicton bed in both cases is altered by a weakly expressed Bwb-horizon. The upper buried soil is overlain by dark brown (oxidized), non-calcareous, thinly-bedded loamy medium sand, loam to silty clay loam, and loam. The surface soil solum extends to a depth of about 0.8 m. It exhibits a weakly to very weakly expressed soil truncated by two plow horizons.

Core 10DK-07 exhibited about 5.1 m of coarse grain fluvial deposits that are interpreted as outwash, overlain by about 2.75 m of alluvial and colluvial deposits. Outwash consists of brown to dark yellowish brown to strong brown (oxidized), non-effervescent, thinly-bedded and locally cross-bedded sand that ranges from very fine to medium sand, with some beds of coarse and very coarse silt loam. Overlying this sequence is a sequence of very dark brown to very dark grayish brown (oxidized), non-calcareous, thinly-bedded loam, sandy clay loam, and sandy loam. The surface soil is cumulic, with multiple black Ap-horizons and multiple very dark brown to very dark grayish brown A-horizons to a depth of about 1.4 m.

Three OSL samples were collected, one collected from each of the cores represented on the cross-section (Figure 3). The sample from core 10DK-08 (UIC-2749) proved to be undatable with OSL because of poor precision. The OSL sample from core 10DK-07 came from an interval of outwash at a depth of about 1.3 m below the top of the outwash. It was sampled above medium to coarse sand, and below fine to medium loamy sand. This suggests the sample was from the middle of an upward fining sequence. The OSL assay yielded a date of 38,180±3815 OSL age yrs. (UIC-2759; Table 2). At face value, this date suggests the upper half of outwash is middle Wisconsin in age. This date may provide a minimum age for the catastrophic flood responsible for shaping the erosional residuals to the immediate north and northeast if the valley in which the dated outwash accumulated was cut during the responsible catastrophic flood.

The location of core 10DK-09 was re-cored and an OSL sample was collected from the top of outwash at a depth of between 1.22 and 1.86 m (Figure 3). The OSL assay yielded a date of 17,680±1540 OSL age yrs. (UIC-2751; Table 2). At face value, the date is Late Wisconsin in age, and provides a minimum age for the flood responsible for scouring the erosional residual upon which core 10DK-09 was collected. Again, at face value, the age seems relatively young to occupy such a relatively high local landscape position. A possible alternative hypothesis is that the loamy sand is a coarse loess facies, and the date could represent the onset of local loess accumulation immediately following scour and outwash sedimentation.

Rich Valley is currently a dry valley that once carried glacial meltwater southeastward away from the position of the stagnating St. Croix Moraine, and possibly the southeast flank of the Grantsburg Sublobe ice front position north of the St. Croix Moraine. Rich Valley is coincident in this local area with a mostly-filled bedrock valley. Where sampled, the northeast wall of Rich Valley is bedrock-controlled, while the southwest valley wall is drift-controlled. Up-valley, the topographic Rich Valley diverges from its buried bedrock valley, essentially at the St. Croix Moraine front. The up-valley end of Rich Valley rapidly disintegrates in the supraglacial landscape of the St. Croix end moraine.

The Rich Valley cross-section (Figure 4) illustrates the graphic sediment soil log of core 10DK-01 and tentative correlations to units described in county well logs. This cross-section augments one constructed up-valley that interpreted subsurface Des Moines Lobe outwash with a high percentage of Superior lobe igneous and metamorphic pebbles (Mossler 1990b, Hobbs et al. 1990).

Core 10DK-01 exhibited two sets of alternating fluvial deposits and sandy clay loam diamicton (Figure 4). Both diamicton beds are interpreted as glacial tills, and the sands are interpreted as outwash. The lowermost till overlies the bedrock valley floor, and is a yellowish brown (oxidized), calcareous, extremely firm, sandy clay loam diamicton. Outwash that overlies this till consists of yellowish brown (oxidized), calcareous, bedded, pebbly fine to coarse sands. Overlying this lower outwash is another diamicton(s), which is mostly a very dark gray, calcareous, extremely firm glacial till. Oxidation of both the upper and lower margins of this till were attributed to weathering (7.5YR 4/4-5/4-3/3 Munsell colors); however, whether this till unit could be further subdivided would require further analyses. The younger, second outwash unit overlying this upper till consists of brown to yellowish brown (oxidized), calcareous, bedded, pebbly fine to coarse sands.

Absolute dating was attempted on this core. A radiocarbon assay from the upper till was beyond the laboratory's half-life limits. Further analysis of a split of the submitted sample under an SEM indicated the carbon was from an ancient coal fragment, and therefore was detrital and not a representative date. The two outwash units were resampled for the collection of OSL samples. An OSL assay on the lower outwash sample yielded a date of 176,540 ± 17,350 OSL age yrs. (UIC2766; Table 2; Figure 4). At face value, this date suggests the outwash is Illinoian in age with a till that predates the age. At face value, the two OSL ages indicate that the bedrock valley is pre-Wisconsin in age. Remnants of severely eroded and weathered Pre-Wisconsin drift are preserved in dissected bedrock upland terrain to the south, so an Illinoian age is possible.

The upper outwash yielded a date of 35,460±180 OSL age yrs. (UIC2767; Table 2; Figure 4). At face value, this date suggests the upper outwash is middle Wisconsin in age, and that at least one till unit dates to the late Illinoian or early to middle Wisconsin. The date is in the same range as the OSL age from core 10DK-07 suggesting that if the ages are appropriate, they are dating the same body of outwash. Further discussion and implications of the two OSL ages from core 10DK-01 are pursued in Hudak et al. (2011).

The four cores taken on the VOP exhibit thinly and faintly bedded coarse grain material that progressively becomes finer down-valley (Figure 5). In individual cores, the upper one to two meters or so fine upward as well. Where sampled closest to the Des Moines Lobe, the sediment consists of brown (oxidized) very coarse and coarse sand with pebble gravel, including abundant clasts of shale, with few thin pebble gravel beds. Pebble content and thin gravel beds become more infrequent with distance down-valley. Where sampled at greatest distance from the Des Moines Lobe, the sediment assemblage consists of brown to yellowish brown fine to medium sand, with rare to common very thin beds of medium to coarse sand. For the most part, the sediment assemblage is oxidized and non-effervescent. An exception occurs in 10DK03 where pebbly medium sand and medium to coarse sand that grades upward to medium sand with pebbles is unoxidized with very dark gray colors, and a calcareous basal bed. It is possible that in this location, a former channel was encountered. Alternatively, aspects of the geomorphic setting of the core may influence the weathering. Core 10DK-03 is situated immediately downstream of an ice block meltout wetland basin, and it also is opposite the mouth of a former meltwater valley.

In this position, the surficial sediment capping the outwash sequence in core 10DK-03 consists mostly of about 1.4 m of calcareous mucky peat and a bed of lacustrine, calcareous, silty marl. Whole and fragments of mollusk shells are abundant in the silty marl, and in the immediately underlying mucky peat bed. The other two up-valley cores, 10DK-04 and 10DK-02, exhibit evidence of surficial wetlands as well, albeit wetland sediment is much thinner, while the down-valley core, 10DK-05, does not. In core 10DK-04, a thin bed of non-effervescent fibric peat overlies a thin bed of olive gray (deoxidized), non-effervescent, coarse silt loam lacustrine sediment that extends to a depth of at least 0.4 m. In core 10DK-02, a bed of non-effervescent muck extends below the depth of a plow zone horizon and overlies gray (deoxidized), non-effervescent, silt loam. The deoxidized weathering zone extends into underlying outwash sand to a depth of about 1.5 m. In core 10DK-05, two plow zone horizons are cut into black and very dark brown, non-effervescent, sandy loam to loamy sand at the top of the outwash sequence. It is possible that a dusting of loess is incorporated into the plow horizons. The subsoil is oxidized.

In core 10DK-03, one mucky peat bed at a depth of about 1.2–1.4 m, near the base of the wetland sediment, had uncarbonized leafy plant material that yielded a radiocarbon age of 1810 $\pm$ 40 C^{14} yrs. B.P. (1750 cal. yrs. B.P.; Beta-279897; Table 1; Figure 5). The wetland is late Holocene in age, and probably reflects a period of higher water table, particularly when compared to the preceding middle Holocene dry period. The higher water table apparently intersected lower positions of the VOP in the upper to middle reaches of the Vermillion Valley, but not in the lower reach.

Four OSL ages and one additional radiocarbon age were obtained from outwash in cores 10DK-02, -03 and -05 (Tables 1 and 2; Figure 5). A sample collected from near the base of core 10DK-04 proved to be too coarse in texture for OSL dating. The additional radiocarbon sample was collected from core 10DK-03. At a depth of about 2.6 m, an organic-rich silty clay loam lens yielded a radiocarbon age of 18,020 $\pm$ 70 C^{14} yrs. B.P. (21,480 cal. yrs. B.P.; Beta-279898; Table 1; Figure 5). An OSL sample collected at a depth between 3.7 and 4.9 m from the same core as the radiocarbon samples yielded a date of 18,890 $\pm$ 1635 OSL age yrs. (UIC2663; Table 2; Figure 5). With the maximum standard errors considered, these two ages from core 10DK-03 are still slightly out of stratigraphic order.

One OSL sample was collected from core 10DK-02 at a depth between 2.4 an 3.7 m. The sample yielded a date of 28,210 $\pm$ 3370 OSL age yrs. (UIC2755; Table 2; Figure 5). Two OSL samples were collected from core 10DK-05. A sample collected at a depth of 7.8 - 7.9 m yielded a date of 26,885 ± 3580 OSL age yrs. (UIC2764; Table 2). The sample collected at a depth between 2.4 and 3.7 m yielded a date of 25,080 ± 1920 OSL age yrs. (UIC2754; Table 2). The two samples are in stratigraphic order.

Core 10DK-10 is down-valley of core 10DK-05 and was taken on a slightly higher, flood-modified, terrace (OTF-16; Figure 2). The outwash sediment assemblage consists of brown to yellowish brown (oxidized), non-effervescent, medium to coarse sand (Figure 6). Few pebble gravel clasts were observed between about 1.2 and 3.1 m, with a few well-rounded exotic pebbles observed between 2.4 and 3.1 m. In the upper meter, the sequence fines upward from brown to strong brown (oxidized), non-effervescent, fine sand to black sandy loam altered by an A-horizon and plow zone horizon.

The outwash sediment sequence here does not continue the fining trend with distance from the Des Moines lobe. Either the OTF-16 LfSA is entirely different from the OT-15 LfSA, or, as OSL ages from the OTF-16 LfSA suggest, it is from a different source valley. Two OSL ages were obtained from core 10DK-10 (Figure 6; Table 2). The lower OSL sample was collected at a depth of between 6.1 and 7.3 m and yielded a date of 21,995 ± 4550 OSL age yrs. (UIC2761). The upper OSL sample, from a depth of between 1.2 and 2.4 m, yielded a date of 25,420 ± 3070 OSL age yrs. (UIC2762). The two ages appear inverted in relation to stratigraphic order, but given the substantial standard error on both, the real ordering is indeterminate.

OSL and radiocarbon ages from the VOP and the slightly higher flood-modified OTF-16 LfSA collectively suggest that the OT-15, OTF16, other locally related flood-modified surfaces, and most likely the OT-20 LfSAs have a common sediment assemblage of Late Wisconsin age, albeit potentially from two different sources. The body of outwash where sampled in the Vermillion Valley beneath these surfaces (OT-15, OTF-16) appears to date minimally between about 28ka and 18ka, taking the OSL ages at face value. The 28ka age estimate is perhaps somewhat early for Late Wisconsin outwash, particularly from the Des Moines Lobe, although there is little, if any, evidence for the age of the earliest late Wisconsin outwash in the UMV. If the ages are accurate, however, the earliest increments of sand may reflect an increase in sediment yield in response to severe climatic conditions in advance of Late Wisconsin outwash into this part of the basin. There are remnants of at least two older outwash units preserved in buried bedrock valleys, one Middle Wisconsin in age, the other Illinoian in age. The VOP is inset into the ROP; collectively the ages suggest that the VOP is initially erosional, cut into the ROP LfSA, with only perhaps up to a few meters of its own sediment assemblage atop the ROP. We did not sample (or rigorously map) the ROP, and it is yet unknown what increments of the ROP are actually associated with, or pre-date, the St. Croix moraine.

Given the antiquity of the OT-15 (VOP) LfSA, pre-Paleoindian and younger prehistoric cultural deposits can be expected to occur on unmodified surfaces. However, it is notable that there has been little headward incision of the Vermillion River, no large-scale removal of terraces in the Vermillion Valley, and only underfit, often dry, streams in tributary valleys that have the VOP as the valley floor. We suggest that this evidence points to a relatively low water table in the early and middle Holocene at least, with relatively little discharge available to transport sediment out of the basin. This may explain, at least in part, the paucity of sites on the VOP and ROP away from the Mississippi Valley.

Down the Mississippi Valley, well logs and NRCS-mapped soil series suggest that the OT-15 LfSA in the Mississippi Valley proper is a similar coarse grain outwash. The implication is that maximum outwash aggradation in the UMV, perhaps preceded by non-glacial aggradation, collectively occurred between about 28ka and 20ka. This is in line with radiocarbon-based age estimates for the timing of Ancient Mississippi Valley aggradation when the Mississippi River occupied the middle and lower Illinois River Valley prior to its diversion to the current Mississippi Valley along western Illinois above St. Louis (Hajic 1990a). Stated differently, Late Wisconsin outwash aggradation occurred during the first half or so of the Late Wisconsin during advance of glacial lobes.

One of the modifications of outwash surfaces in the Vermillion Valley is deposition of eolian dunes. The medial part of one of the eolian dunes along the east side of Sand Coulee was cored (10DK-06; Figure 2) to date the base of the dune. The dune consists of at least 2.5 m of strong brown to brown (oxidized), non-effervescent fine to medium sand. An OSL sample collected from eolian sand at a depth between 1.2 and 2.4 m yielded a date of 3415 ± 350 OSL age yrs. (UIC2756; Table 2).

At face value, the OSL age suggests the dune is early-late Holocene in age. This age is more than several centuries younger than the youngest period of major dune reactivation documented on the Anoka Sand Plain not far to the north. Keen and Shane (1990) dated this youngest period to sometime between 5100 and 4000 C^{14} yrs. B.P. If accurate, the OSL age suggests that movement of Holocene eolian sand may not be exactly synchronous in the region, but certainly relatively closely timed.

6.2 Area 2: OT15 LfSA Slackwater Facies 1

Significant to understanding the archaeology of the OT15:22 terrace is the fact that the terrace exhibits a sediment assemblage and age in the lowest reach of tributary valleys south of the Vermillion Valley than in that valley and the UMV. Unable to keep pace with aggradation in the Mississippi Valley, slackwater lakes were impounded in the lowest reach of tributary valleys as outwash dams blocked tributary valley mouths. Slackwater silt and clay accumulated in the lakes, burying the paleogeomorphic surface that was temporally equivalent to the OT15:22 surface in the Mississippi and Vermillion Valleys. Where remnants of the sediment dam are preserved, the OT15 LfSA consists of coarse grain outwash, and the surface can be expected to be about 18 – 20ka old. The OT15 surface, where developed upon slackwater lake sediment in the lowest reach of tributaries, is considerably younger than the OT15 surface in the Mississippi and Vermillion Valleys.

The OT-15 terrace is equivalent to the Savanna Terrace, originally defined on the basis of elevation and associated soil series (Flock 1983). Where terrace formation by incision is dated (Hajic 1990a), in the Savanna-equivalent Deer Plain Terrace in the lower Illinois Valley, it is about 12,200 C^{14} yrs. B.P. In the same location, aggradation of the sediment dam continued to about 13,000 C^{14} yrs. B.P., with overbank clay accumulating presumably until the breaching of the dam in response to incision of the Mississippi River considerably later. While the age of terrace formation pre-dates the Paleoindian period, the slackwater lakes may have played a role in pre-Paleoindian use of the landscape.

The slackwater facies of the OT15 LfSA was sampled in both Areas 2 and 3 in an attempt to recover datable material to illustrate the temporal relationship of the slackwater facies to the outwash facies of the LfSA. Area 2 is the lower reach of East Indian Creek, an intermediate order valley just up-valley from the Whitewater River Valley (Figure 7). Core 10WB-01 was taken three kilometers up the valley on the distal part of a colluvial slope (MC2:22). In this location, bedrock, probably weathered sandstone, is at a depth of about 10.7 m. It is overlain by a thin increment of coarse grain slackwater or alluvial sediment followed by up to about 0.8 m of fine grain slackwater deposits. Overlying colluvium is interstratified with thin beds to thin laminae of slackwater sediment (Figure 8).

Laminar to thinly bedded, non-effervescent, grayish brown (deoxidized) sandy clay loam, and strong brown very fine sandy loam lie at the base of slackwater deposits (Figure 8). There are several possible interpretations for these coarser beds. They may simply represent alluvial deposits of East Indian Creek. Alternatively, they could be associated with the distal facies of an advancing delta into the head of the nascent slackwater lake. In any case, brown (oxidized), slightly effervescent, laminated silt loam slackwater deposits overlie them.

A thin bed of light yellowish brown (oxidized to deoxidized), slightly effervescent, massive sandy clay loam diamicton marks the basal colluvium. There are angular fragments of local bedrock. The unit is interpreted as a mass wasting deposit, perhaps fostered by permafrost conditions. Overlying colluvium consists mostly of yellowish brown to brown (oxidized), slightly effervescent, massive to laminar and thinly bedded silt loam and fine silt loam. Throughout nearly the entire colluvial sequence, there are beds and laminae of slackwater sediment. This material consists of gray to pinkish gray (deoxidized) silt loam and weak red (10R 5/4; oxidized) silty clay loam. Interstratified slackwater sediment also rarely includes thin laminae of brown (oxidized) fine sandy loam. It is also possible that some of the laminated yellowish brown silt loam is slackwater in origin. The surface soil exhibits an A–Bt profile that is most likely developed in colluvium.

The weak red, pinkish gray and other colors with distinctly reddish hues are a characteristic of the slackwater facies of the Savanna Terrace (Flock 1983). Laminae with these colors reflect contributions of material with a Lake Superior basin source that were back-flushed up tributary valleys. Rarely, this material occurs as a bed, probably reflecting a large magnitude flood down the UMV with a strong contribution ultimately from a Lake Superior source. One such bed occurs in core 10WB-01at a depth of 2.81–2.84 m.

No datable organic material was observed in core 10WB-01.

6.3 Area 3: OT15 LfSA Slackwater Facies 2

Area 3 is located in the lower reach of Stockton Valley, occupied by Garvin Creek (Figure 9). This valley was selected for sampling because there was the potential to sample the slackwater terrace facies of both the OT15:22 LfSA and a lower terrace LfSA at the junction of Garvin Creek and Rollingstone Creek. Mapped soil series suggested that Superior Basin-source reddish brown clay was present in both sediment assemblages. Unfortunately, access was unavailable at the latter location.

Core 10WN-01 was collected about 2.7 km up Stockton Valley at distance from the valley margin and toe of the valley margin colluvial slope (Figure 9). Slackwater sediment is at least 9.27 m thick; the base was not reached before the boring was terminated. The lowest 1.8 m of sampled slackwater sediment consists of dark gray (unoxidized), slightly effervescent, thinly bedded to laminated silt loam. In the upper 0.7 m of this increment, there are common thin laminae fragments of peat. Overlying slackwater deposits consist mostly of laminated to thinly laminated to thinly bedded, slightly to strongly effervescent (variable), silt loam that ranges from light brownish gray to light gray (deoxidized), upwards to brown to yellowish brown (oxidized). Distinct brown to pinkish gray silt loam with a Lake Superior Basin source component was evident between about 6.1 and 7.5 m in depth. Silt loam is rarely interbedded or interlaminated with the clay loam, and on two occasions in this core, was interbedded with fine pebbly silty clay loam with exotic pebbles. The uppermost 2.0 m is finer grain in texture, consisting of grayish brown downward to brown to yellowish brown silty clay to silty clay loam. While some of the clay content can be attributable to pedogenic clay translocation, its presence for the most part reflects a fining of the slackwater deposits. The surface soil exhibits an Ap–Bt–BC profile.

One radiocarbon age was obtained from the peat recovered at a depth between 7.54 and 8.18 m. A very delicate and intricately webbed fiber from a single wetland plant was collected under magnification. This plant yielded a conventional radiocarbon age of 18,750 ± 70 C^{14} yrs. B.P. (22,350 cal. yrs. B.P.; Beta-279002, Table 1; Figure 10). This age is toward the later stages of accumulation of the outwash facies of the OT15:22 LfSA. The overlying 7.5 m of slackwater sediment post-date this age, and pre-date catastrophic flood incision in the UMV.

6.4 Area 4: Bedrock Valley Reach

The first area is located in a bedrock valley that presumably functioned as a bedrock channel for floodwaters of the youngest catastrophic flood, although the bedrock valley/channel was established prior to this flood. Grotes Pond occupies the mouth of the bedrock valley (Figure 11). The town of Frontenac is situated on a catastrophic flood bar (CB8:22 LfSA) in the downstream end of this bedrock channel. Locally, the highest terrace within the bedrock valley is the OT14:22 LfSA, with additional flood bars at the CB8:22 level that rise above the CPC8:22 and CPC7:22 paleochannel levels. Wetlands occupy much of the former thalweg of the paleochannel (CPCMA>>3:22; CPCW3:22).

Three cores were taken in the bedrock valley. Two were located on alluvial fans, and one on a colluvial fan (Figure 11). Two were on relatively small fans deposited by short, low order tributary valleys along the bedrock valley. The third core sampled the proximal alluvial fan at the mouth of the bedrock valley. This latter fan was deposited by Wells Creek which from the south joins the bedrock valley at its mouth after cutting through terraces related to the bedrock valley.

Core 10GD-02 yielded the most complete sequence of the three cores because it penetrated into fluvial deposits beneath the fan (Figure 12). 10GD-02 was taken on the distal part of the alluvial fan. The core shows a sequence of fluvial deposits overlain by wetland deposits and capped by alluvial fan sheetflood deposits. In the lower fan, sheetflood deposits interfinger with finer grain lacustrine deposits. We attribute this sequence to waning flow of the St. Croix Valley flood(s) followed by wetlands in the entrenched channel that were fed primarily by groundwater, followed by progradation and burial by an alluvial fan. Finer grain lacustrine deposits represent periods of high lake stands within the relict thalweg.

Waning catastrophic flood deposits consist of grayish brown to dark grayish brown (deoxidized), calcareous up to non-effervescent, coarse sandy gravel that fines upward over about 2.9 meters to fine loamy sand. Pebble gravel consists of both well rounded exotic, and subangular to well rounded local lithologies.

A log rests on the surface of the waning flood deposits (Figure 12). Wetland deposits are represented by interlaminated black mucky peat and dark gray (unoxidized), non-effervescent, silt loam over a thickness of about 1.3 meters. Faunal trampling or growth of trees may have caused the irregular abrupt boundaries noted in the lower 0.4 m.

Distal alluvial fan deposits are 5.15 m thick (Figure 12) where sampled. The fan sediment sequence reflects initially an interfingering of fan sheetflood sedimentation with wetland sedimentation. This relationship rapidly gives way to fan sheetflood sedimentation interfingering with lacustrine sedimentation. Fan sediments overall become dominate higher in the sequence while overall sediments are deoxidized except for the fan surface soil. Thinly bedded to laminated and slightly effervescent basal fan sediment consists of grayish brown (deoxidized) fine loamy sand and dark gray (unoxidized) silt loam. A black mucky peat bed occurs near the base of the fan sequence. The next younger increment of fan sediment consists of thinly bedded to laminated, slightly effervescent grayish brown and very dark gray silt loam. The very dark gray strata are organic-enriched. An overlying thin bed (1.1 m thick) of massive, very dark gray, slightly effervescent (variable), silty clay loam lacustrine sediment interrupts the alluvial fan sequence. The bed has many mollusk shells. All but the uppermost 0.46 m of the uppermost fan sequence consists of laminated, grayish brown, dark grayish brown and light grayish brown, slightly effervescent, silt loam, with few silty clay loam laminae in the lower part of the increment. A thin bed of dark yellowish brown muck with silty clay loam caps the intact sequence. It has common pieces of broken clam shells and a few whole snail shells.

Core 10GD-01 was taken on a small colluvial fan deposited by a south-facing, steep, first-order drainageway. As a result, fan deposits are coarser than the aforementioned fan. The core bottomed in sandstone or a sandstone boulder at a depth of nearly seven meters. The entire core is non-effervescent. In general, the colluvial fan consists of a basal increment of alternating crudely defined beds of brown and brownish yellow (oxidized) silty clay loam and pebbly sand with cobbles of local bedrock origin. This increment is overlain by light yellowish brown (oxidized), clast-supported to matrix-supported, pebbly medium sand gully washer deposits. Uppermost fan deposits consist of massive to crude thin beds of dark brown (oxidized) loam with weathered pebble and cobble gravel clasts of sandstone and carbonate rock. Thin beds of black loam and very dark grayish brown silt loam to loam, both with weathered pebble gravel, cap the fan sequence. They are altered by a possible Ap-horizon and intact underlying AC-horizon.

Core 10GD-03 was collected on what appears to be the medial alluvial fan. The core location is in line (north–south) with the boundary between the western margin of Lake Pepin, and the eastern margin of the catastrophic flood landform sediment assemblages that occur to the north and south of the mouth of Wells Creek. The core refused at a depth of about 4.4 meters on a cobble in fluvial deposits that are overlain by slackwater deposits. The sequence is capped by nearly 1.7 m of various road beds (the oldest being asphalt), perhaps interstratified with a few fluvial flood beds.

Basal fluvial deposits consist of very dark gray (unoxidized) cobbly up to pebbly coarse sand. Gravel is mostly of exotic origin, with a few well rounded local carbonates. Slackwater deposits consist of dark olive gray sandy clay loam with exotic pebble gravel. Effervescence is spotty. There is a basal thin bed (3 cm thick) of black fine silt.

Origin of the fluvial deposits is equivocal. They could represent the top of the youngest catastrophic flood sediment assemblage. Alternatively, they could be part of an older outwash or catastrophic flood sediment assemblage that was truncated by younger floods of large magnitude. Less likely due to the preponderance of exotic gravel lithologies, they could be relatively young flash flood gravel deposited by Wells Creek. Recovery rate of slackwater sediment was low, so we are uncertain as to how well they are represented. Except for the basal few centimeters, recovered slackwater deposits have a coarse component to them, perhaps representing input from Wells Creek. Perhaps it is more appropriate to think of the sampled part of the Wells Creek fan as a fan delta, rather than an alluvial fan.

Two radiocarbon ages were obtained from wetland deposits in core 10GD-02, one each from the top and bottom of the interval (Figure 12). A piece of uncarbonized log resting on underlying catastrophic flood deposits yielded a conventional radiocarbon age of 10,420 ± 70 C^{14} yrs. B.P. (12,300 cal. yrs. B.P.; Beta-279000; Table 1; Figure 12). From just below the top of the unit, peat plant fibers yielded a conventional radiocarbon age of 8350 ± 40 C^{14} yrs. B.P. (7420 cal. yrs. B.P.; Beta-281005; Table 1). In Core 10GD-03, a modern date was returned on a small black root collected at the base of slackwater deposits of the Wells Creek fan delta.

The apparent time span over which the wetland deposits accumulated at the core location is in line with similar sequences of dated wetland deposits in the UMV where they occur on buried bedrock strath terraces cut at some point by catastrophic flooding (Hudak 2008 2010, and 2011). It appears that after the youngest catastrophic flood down the UMV, the river level was relatively low, confined to an inner bedrock gorge. At the same time, wetlands developed on higher valley margin landscape positions, suggesting they formed and were fed by groundwater seeping from bedrock sources. Whereas either lacustrine deposits of Lake Pepin or Mississippi River alluvium bury wetlands on bedrock benches, the wetland at the core location was buried by alluvial fan or related local alluvium. The timing of this burial and onset of alluvial fan sedimentation is also in line with the initiation of a general period of rapid growth of Midwestern alluvial fans (Hajic 1990b).

The origin of the log has a bearing on the interpretation of its age at the location of 10GD-02. It is possible that the log was a casualty of the catastrophic flood, redeposit in its location as part of the post-flood drift. Alternatively, the log may represent post-flood growth locally. If the former is the case, the age pre-dates the flood slightly. In the latter case, the age post-dates the flood somewhat. In either case, large magnitude flood flow coursed through the bedrock valley within several hundred years on either side of the Pleistocene–Holocene transition. In both cases, there are obvious implications for the location, preservation and absence of Paleoindian cultural deposits in the bedrock valleys, and the UMV in general.

6.5 Area 5: Small Coulee Alluvial Fans

One of several small alluvial fans at the margin of the Holocene-aged Mississippi Valley was cored in an attempt to date the sediment assemblage upon which it was deposited (Figure 13). The fan was deposited at the mouth of a small coulee that developed into the CT8:22 LfSA and older alluvial or debris flow fans (MAFV3:22 LfSA). The fan deflects the Vermillion River as it flows through a catastrophic marginal flood channel opposite the head of Prairie Island, a catastrophic flood bar. We chose this location because we suspected the youngest large magnitude flood(s) emanating from the St. Croix Valley probably utilized this marginal flood channel, although it most likely was originally cut by flood flow from the Lake Agassiz basin.

Just beyond the mouth of the coulee, core 10DK-12 was taken on the proximal alluvial fan (Figure 13). The sediment assemblage consists entirely of non-effervescent coarse grained alluvium interpreted to represent alluvial fan deposits atop a flood sequence floored by coarse gravel at the base of the core. The core barrel refused on gravel at a depth of 14.6 m, probably on cobble or boulder gravel. Above this is a crude upward fining sequence. At its base is brown to dark brown (oxidized) very coarse sand to gravel with many exotic well-rounded gravel clasts along with very few angular pieces of carbonate rock. Similarly colored medium to coarse sand caps the upward fining flood sequence.

The alluvial fan sediment assemblage is initiated with a series of at least four overall coarse fining-upward sequences that cumulatively are at least 1.8 m thick, and most likely closer to 3.0 m thick (Figure 14). Upward fining sequences generally consist of brown to dark brown (oxidized) very coarse pebbly sand that fines upward to fine loamy sand. The impression is that these accumulated relatively rapidly. The overlying 4.0 m or so consists of thin beds of brown, dark brown, and yellowish brown (oxidized) very coarse, coarse, medium and fine sand with sorting ranging from poor to well sorted; and, medium to coarse and very coarse sand with pebbles, and very fine to fine loamy sand with few pebbles. Several additional fining-upward sequences are present. The upper 5.1 m of the alluvial fan sediment assemblage overall consists of finer coarse grain deposits than the underlying increment. The lower 3.6 m consists primarily of yellowish brown, dark yellowish brown, brown and dark brown medium (oxidized) loam, very fine sandy loam, medium sandy loam, and loamy sand with and without pebbles. The uppermost 1.5 m of this increment consists almost entirely of four upward fining sequences. Colors range from black and very dark grayish brown to brown (oxidized). Basal textures of upward fining sequences range from medium sandy loam to very coarse pebbly sand. Upper textures range from silt loam to fine pebbly sand. The surface soil exhibits an Ap–C horizon.

One OSL sample was collected at a depth of 11.40 – 11.50 m from near the base of the alluvial fan deposits, and one radiocarbon sample was collected at a depth of 9.13 - 9.23 m (Figure 14).

The radiocarbon sample consisted of organic stains in laminae. The OSL sample yielded a date of 5300 ± 580 OSL age yrs. (UIC2750; Table 2). The overlying radiocarbon sample yielded an age of 9770 ± 50 C^{14} yrs. B.P. (11,200 cal. yrs. B.P.; Beta-279899; Table 1; Figure 14).

The ages are inverted. Of the two samples, we think the OSL age is suspect; it does not fit current geological and landform interpretations or models of landscape evolution, all of which involve a number of other radiocarbon ages. We are uncertain what may have caused the younger age. It is possible that the interpretation of the moisture content history of the sample, a variable critical for OSL dating, was not well defined. On the other hand, the radiocarbon sample from core 10DK-12 is just younger than the catastrophic flood that coursed down the St. Croix Valley (Hudak and Hajic 1999). The flood caused incision in the Mississippi Valley, resulting in the tributary response of coulee incision by headward erosion, with eroded material accumulating in the alluvial fan.

7 Synopsis of History of Landscape Evolution

In this section, we focus on our mapping, stratigraphic and dating results, rather than repeat aspects already presented in the introductory review. The fieldwork adds information on the timing and development of the initial early – Late Wisconsin filling of the UMV with outwash. It also adds to the body of data pointing to a decisive very early Holocene flood event that reset the landscape clock for both the Mississippi Valley and its tributaries.

Geomorphic assessment and a few OSL ages record evidence for a previously undocumented large magnitude flood that coursed through the UMV. Based on landscape position and surrounding geomorphic surfaces, this flood must pre-date Lake Agassiz discharges, and may well predate some or all of the accumulation of early Late Wisconsin outwash. The orientation of streamlined landforms points to a north to south direction of flood flow. The outwash plain surrounding the higher streamlined hills was scoured by later floodwaters that flowed through gaps in the hills. Whether this modification of the outwash surfaces was the result of spillover of catastrophic flood waters down the St. Croix Valley as suggested by the orientation of the scoured surfaces, catastrophic flood waters down the Minnesota Valley, or some earlier event that pre-dates incision of the highest outwash surfaces, is unknown. If the latter is the case, scouring discharge need not necessarily have been a flood of catastrophic magnitude. If an earlier adjustment in the glacial meltwater system occurred before the OT15:22 LfSA was deeply incised and largely removed from the UMV, then it might explain the OT15:22 – OT14:22 relationship seen in the mouths of many tributary valleys, particularly lower in the study reach. The OT14:22 LfSA surface, related to activity in the Mississippi Valley, truncates the tributary OT15:22 surfaces where they are developed in the valley mouth sediment dam facies. OT14:22 surfaces are inset only slightly below the level of the OT15:22 surfaces. OT14:22 surfaces rarely are found up tributary valleys more than a kilometer or so beyond the valley mouth.

OSL and radiocarbon ages from outwash LfSAs in the Vermillion River Valley suggest that outwash started accumulating by at least as early as about 28ka years ago. It is possible that the earliest increment of the sediment assemblage is technically not outwash, but rather the result of high sediment production with the onset of cooler climatic conditions. In any case, thick sand and gravel from the Lake Superior lobe and the Des Moines lobe accumulated to its maximum level by about 20ka years ago. Based on OSL ages and geomorphic relationships, this approximates the time when the Lake Superior lobe attains the position of the St. Croix end moraine. This estimate agrees with the earliest age proposed by Mickelson et al. (1983). Discharge from at least the Des Moines lobe caused incision of this highest outwash plain to the level of the OT15:22 surface. Based on the array of OSL ages, and in particular the one old radiocarbon age from the outwash sediment assemblage, the OT15:22 surface dates to about 18ka or slightly younger.

Only a few remnants of the OT15:22 outwash plain are preserved in the UMV proper, having survived subsequent catastrophic flooding. However, during aggradation in the UMV, tributaries that received Des Moines lobe outwash aggraded to this level as well. Remnants are discontinuously preserved in upper and middle tributary reaches, particularly in what were basin areas. Equivalent remnants of the VT15:22 LfSA are preserved in tributary valleys that did not receive outwash, attesting to the high sediment production in tributary basins under periglacial conditions at the time. In lower reaches of nearly all but the smallest tributary valleys, remnants are preserved that represent sediment dam and younger slackwater facies of the OT15:22 LfSA.

During aggradation of the OT15:22 and VT:22 LfSAs, valley slopes were actively eroding and colluvial LfSAs MC1:22 and MNR:22 were accumulating, and MNH:22 was eroding into hillsides. It appears that these conditions of hillslope wasting, colluvial sedimentation, slackwater accumulation behind sediment dams at the OT15:22 level, and maintenance of the UMV valley surface at the OT:15 level, lasted for some length of time, that at a maximum would be about six thousand years. It is inconceivable, however, that a system such as the UMV would not be effected by changes in discharge and sediment yield in response to glacial fluctuations during such a long interval. Unfortunately, evidence for such changes in the UMV during this interval has been removed by subsequent events, and the chronology of tributary valley terrace LfSAs has yet to be resolved beyond the relative relationships provide by the initial correlations made for this project. Detailed assessment of the OT15:22 slackwater lake sedimentology may provide some clues to Mississippi River behavior during this interval.

Massive valley incision due to catastrophic flood flow(s) from Glacial Lake Agassiz was a seminal event in reshaping the pre-existing UMV geomorphology and the landscapes in tributary valleys as they responded by downcutting. The actual age of flooding is not precisely known, but catastrophic discharge pre-dates about 10,800 C^{14} yrs. B.P. (12,680 cal. yrs. B.P.) (Fisher 2003). The latest large magnitude discharges had to occur after the advance of the Grantsburg sublobe, or after about 11,900 C^{14} yrs. B.P. (13,760 cal. yrs. B.P.). Down-valley, geomorphic, stratigraphic and radiocarbon evidence from the vicinity of St. Louis, Missouri, suggests incision due to Glacial Lake Agassiz discharge occurred around 12,200 C^{14} yrs. B.P. (14,050 cal. yrs. B.P.). Massive valley incision during this temporal window would have effectively voided at that time potential evidence in the valley for the earliest Paleoindian and any pre-Paleoindian cultural deposits. A number of new terrace surfaces were constructed during the flood(s), largely by erosion into the pre-existing outwash sediment assemblage. These surfaces are represented by the Catastrophic Flood LfSAs. This interval is the earliest opportunity for the scouring of the outwash terrace surfaces in the mouth of the Vermillion River Valley, and cutting of the erosional scarp on the south side of the Vermillion Valley mouth. Deposition of the debris flow fans (MAFV3:22 LfSA) would have shortly followed, with subsequent incision of Sand Coulee and other smaller coulees into the outwash terraces in the Vermillion Valley mouth.

A younger, smaller, yet still catastrophic flood(s) impacted the UMV below the mouth of the St. Croix Valley (Hudak and Hajic 1999, Hajic and Hudak 2005). Down-valley in the vicinity of St. Louis, Missouri, this flood was documented to have occurred around 9850 C^{14} yrs. B.P. (11,250 cal. yrs. B.P., Hajic 1990a). Radiocarbon ages from this project appear to confirm that this flood occurred before 9770 C^{14} yrs. B.P. (11,200 cal. yrs. B.P.; see core 10DK-12). The earliest this flood(s) could have occurred, based on radiocarbon evidence from LfSAs related to the flood, is between about 10,400 and 10,100 C^{14} yrs. B.P. (12,270 and 11,700 cal. yrs. B.P.; Hudak and Hajic 1999 and 2005, Hajic and Hudak 2005, Hudak 2008 and 2011, Hudak et al. 2011, and this report). This slightly earlier timing hinges on whether the dated woody material represented older growing stands and deadfall that was ripped up and redeposited by the flood(s), or represented early post-flood(s) growth. This flood, emanating from the Lake Superior basin via the Kettle and Brule Rivers, carved the St. Croix valley walls as they exist today, and would have impacted the UMV. However, we think in the UMV, the impact was limited to landscape positions at and lower than the lowest surfaces formed during the earlier catastrophic flood(s). Hudak (2008, 2010, and 2011) has documented an inner bedrock gorge in the floor of the UMV. Deeply buried bedrock benches upon which early Holocene fluvial and wetland deposits accumulated flank the gorge. Hudak (2008, 2010, and 2011) has dated this sequence between about 9900 and 7600 C^{14} yrs. B.P. (11,300 and 8400 cal. yrs. B.P.). Whether or not the earlier catastrophic flood(s) originally cut the buried bedrock landscape, it certainly was modified by up to the level of the bedrock channels downstream of Red Wing by the younger St. Croix Valley flood(s). We suspect that immediately after this younger flood, the very early Holocene Mississippi River was confined to the inner gorge, flowing at a much lower level than today. Tributaries would have responded, probably in a complex manner, by headward erosion and incision, resulting in some of the youngest generations of tributary valley terraces. The St. Croix flood(s) effectively would have voided evidence of any potential Paleoindian cultural deposits on the floors of the bedrock valleys and on lower landscape positions in the UMV. Any evidence of Early Archaic utilization of low landscape positions exposed in the wake of the flood for the most part now is buried, and in some cases very deeply buried. In the tributaries, there ought to be terrace levels, perhaps the VT4 or VT5 LfSAs, upon which only Early Archaic and younger cultural deposits should be expected; they are too young to have associated buried Paleoindian deposits.

Subsequent evolution of the UMV involved filling of the bedrock gorge, tributary creek activity along valley margins, and floodplain establishment and modification. The formation and history of Lake Pepin, a valley lake of perhaps multiple phases is reported by Zumberge (1952) and Blumentritt et al. (2009). Lake Pepin formed as growth of the Chippewa River alluvial fan impeded flow of the Mississippi River. Lake waters rose to the point where they presumably reached the City of St. Paul. The Mississippi River developed a delta that eventually prograded down-valley into Lake Pepin. Eventually, from upstream to downstream, flood basins behind the prograding delta filled and distinct suites of various floodplain landforms were established, often interacting with extensions of tributaries beyond their valley mouths. This generalized scenario may not have been limited to the Chippewa River fan and Lake Pepin. It may well have been repeated down-valley by the development of valley lakes behind other fan deltas and alluvial fans from larger tributaries. Down-valley, however, evidence of these hypothesized is not documented, perhaps because they were of smaller extent. In any case, the current location of the active Lake Pepin delta, represented by deltas flanked by flood basin, is in the valley reach between Red Wing and Wacouth. Up-valley at Pig's Eye Island, opposite the St. Paul Downtown Airport, the Mississippi River natural levee buries a cultural deposit that yielded a radiocarbon age of about 3100 C^{14} yrs. B.P. (3320 cal. yrs. B.P.). Given the prograding nature of the Mississippi River delta, the basal age of the main natural levee ought to decrease down-valley, with obvious implications for the oldest cultural deposits that can be expected to be in association. If indeed multiple Mississippi River delta levees were prograding simultaneously in different reaches of the valley, this complex relationship between cultural and delta levee deposits can be expected. The presence of one or more valley lakes filling over the course of the Holocene suggests that large volumes of valley fill, once defined, can be excluded from consideration of buried prehistoric cultural deposits. It further suggests, however, that the documentation of valley lake levels and particularly valley lake margin positions through time would be an important tool for locating prehistoric sites that focused on lacustrine resources, and in more general terms, documenting limits of potential settlement. Given the history of Valley Lake infilling through the Holocene, prehistoric cultural deposits associated with former lake margins for all but the latest Holocene time period and steep terrace margins abutting lake waters will be buried. For the most part, older prehistoric cultural deposits will be more deeply buried than younger cultural deposits except on original post-flood terraces and bedrock straths that are now buried.

Initially post-flood, tributaries would either have entered directly into Lake Pepin, other valley lakes, or the Mississippi River, or flowed across catastrophic flood surfaces before entering the aforementioned. As Lake Pepin filled, the courses of some of these tributaries changed considerably. Perhaps the strongest example of this is the Vermillion River. Originally, it flowed into the upper part of Lake Pepin. Subsequently, it flowed along the southwestern valley wall through a marginal flood channel before eventually joining the Mississippi. While in the marginal channel, it shifted course slightly, creating multiple generations of natural levees while capturing the flow of other tributaries. Where tributaries did not flow over older terraces and strath terraces, a potentially even more variable, complex buried sediment record of tributaries can exist. In the lowest flood basin in the project area, Crooked Creek has a complex history based solely on surficial evidence, much less the its earlier buried record. Its surficial course was influenced by first, migration away from the western valley wall by the Mississippi River. Subsequent courses were influenced by its own natural levees in reaches, growth of its own, and other, alluvial fans down-valley, and multiple generations of crevasse splays.

Alluvial fans would similarly have a variable record depending upon the age and elevation of the surface upon which they were deposited. Those deposited on marginal flood channels and other catastrophic flood-related surfaces will exhibit relatively thick sequences representing the entire Holocene. The best example of one of these fans is the Zumbro River alluvial fan. Zumbro River flowed onto the surface of a marginal flood channel, sometimes flowing down-valley, sometimes flowing up-valley, to join the Mississippi River. The result is a substantial alluvial fan in volume, with a minimum overall basal age dating to the St. Croix flood(s), marked by a great number of fan lobes, any of which can be expected to host buried prehistoric cultural deposits dating through at least the Early Archaic. Tributaries that entered Lake Pepin directly, or other inundated flood basins, most likely deposited alluvial fan deltas that would have offered limited opportunities for significant settlements. Eventually, however, nearly all of these transitioned to alluvial fans, probably during the late Holocene. As Lake Pepin filled, flood basins developed, and fans grew during the late Holocene, it appears that the large tributaries decreased their gradients in their lower reaches. In response, they began to aggrade, avulse, develop low natural levees, and migrate laterally. The net result is likely a stratigraphy that is more complex than upvalley, and overall seemingly poorly drained conditions. Aggradation continued into the Historic period as sediment of post-Euroamerican age was effectively deposited across tributary valley surfaces in their valley mouths.

In general, floodplain sediment assemblages are expected to be for the most part Late Holocene in age. This late prehistoric landscape was modified by a substantial component of landforms and veneers that is Historic in age. The sequence of late Holocene evolution of the Mississippi floodplain follows valley filling of a more extensive Lake Pepin and perhaps other valley lakes. The landscape evolution was likely highly dynamic, suggested by the location of the earliest evidence of Mississippi River paleochannels and their subsequent near-obliteration of that evidence. Some of the flood basins also show evidence of previous Mississippi River paleochannels and associated bars. For example, in the lowest flood basin in the project area, the Mississippi River flowed along the western valley wall before moving or jumping eastward. At one point, it developed a bar complex (FBO6:22). In other flood basins, it is evident that the channel migration not only laterally, but translated down-valley as well. In short channel reaches, multiple natural levee sets and evaluation of early valley maps attest to the continuation of channel migration today. Evidence of the older channel shifts is sparse in the form of natural levees, paleochannels and bars, but it is clear that these features influenced the patterning of subsequent depositional modifications. The predominant type of floodplain sediment assemblage appears to be crevasse splay systems. There clearly was an episode of enormous splay sedimentation that was in part guided by the orientation of landforms related to earlier Mississippi channel positions. In other cases, the splays are so massive that there is no indication what they are deposited upon, or that they have any relationship to pre-existing landform trends. Splay sedimentation continued into the Historic period, although it appears to not involve development of expansive splay systems. Distal splay limits tend to define the eastern land-water interface with inundated basins. In other locations, distal splay deposits abut alluvial fans or relict natural levees. At some point following development of the massive splay systems, there appears to have been an attempt at formation of an island-braided floodplain in close proximity to the modern river course. Currently at some locations, small patches of island braided floodplain are being buried by splay and natural levees. Bars in and near the current Mississippi River are on the whole smaller than the scant evidence for older bars associated with paleochannels. They are active, with many evident on historic maps, but rarely of the same form. Some are entirely historic in age.

With installation of the lock and dam system, reservoirs were created that inundated previously exposed floodplain areas. Flood basin dynamics changed, resulting in deposition of extensive and sometimes thick veneers atop older floodplain surfaces. The impression given by the modern floodplain is one of very wet conditions unfavorable overall for significant prehistoric occupations. Prehistorically, overall floodplain conditions may not have been as wet as today, beyond the obvious limitations of the reservoirs, but they may not have been that well drained either. Local highs provided by river and splay levees, relict bars, and distal alluvial fans of the time would be the most likely locations for prehistoric floodplain settlement. Most of these locations have a veneer of sediment of post-Euroamerican settlement age, are inundated, or are characterized by both conditions. Surface sites should be extremely rare, and buried sites the norm. Buried floodplain sites may extend back as old as the Late Archaic period, but could certainly be younger. To better understand the rare floodplain site, any site recorded on the floodplain or buried within floodplain LfSAs ought to be thoroughly investigated for context to confirm they indeed are associated with a floodplain LfSA and not a buried, older LfSA.

8 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 as too old, too young or old enough to host intact prehistoric cultural deposits, and the degree to which depositional environments, based on depositional energy and hydrologic conditions, are likely to bury and preserve intact cultural deposits.

In the UMV and tributaries, mapped landforms of the Glaciofluvial, Catastrophic Flood, and Valley Terrace landscapes at and higher than the OT15:22 LfSA are too old to host buried prehistoric cultural deposits (ages are based upon current archaeological interpretations of the State Archaeologist in Minnesota). Furthermore, these sediment assemblages accumulated in depositional environments unfavorable for occupation. In the Glaciofluvial and Valley Terrace landscapes, depositional environments would not have been conducive to burial or preservation of intact cultural deposits because of the dynamic nature and energy of the braided stream environment, particularly in channeled areas. Similarly, in the Catastrophic Flood landscape, even for LfSAs lower than the OT15:22 LfSA, surfaces are cut into older coarse grain deposits of the Glaciofluvial LfSAs, or comprised wholly or in part of flood deposits. The geologic potential for buried prehistoric cultural deposits greater than the zone of pedogenic mixing on these LfSAs is nil because of the high energy depositional environments and, for all but the youngest catastrophic flood features, the older ages.

Valley terrace sediment assemblages in tributaries from about the VT3 LfSA and younger may be young enough, or have terrace veneer deposits young enough, to host buried prehistoric cultural deposits. Similarly, in the UMV, valley terrace sediment assemblages at the VT2 level and younger are suitable for burial and preservation of prehistoric cultural deposits.

In the Floodplain landscape, a range of landforms are likely too young to host buried prehistoric cultural deposits, particularly in the UMV. The youngest natural levees, crevasse splay systems, island braided and other young floodplain segments, mid-channel bars, and upper increments of deltas and fan deltas are for the most part Historic in age, and the LSR is judged nil on that basis. Overall, the youngest elements of these sediment assemblage groups are more likely to bury and preserve prehistoric cultural deposits, potentially at great depth, in the same depositional environments where they are of appropriate age. Older generations of these types of floodplain landforms have a higher LSR because they are generally low energy depositional environments, and most likely of late Holocene age. But mapped soil series suggest many of these have a veneer that is Historic in age. Some floodplain sediment assemblages will be time-transgressive, particularly the natural levees associated with Lake Pepin. Other similar lakes may have existed down-valley, and their levees may show a time-transgressive pattern, becoming younger down-valley.

The highest valued LSRs occur where eolian dune, colluvial slope and floodplain LfSAs are of appropriate age. These depositional environments are conducive to burial and preservation. For the eolian dune and colluvial slope LfSAs, the ranking may be even greater where they bury terrace surfaces that have been exposed for extended intervals of the Holocene prior to burial. Even younger cultural deposits can be buried where dunes on terraces were reactivated during Historic time. In the tributary valleys, Type X, Type Y and Type Z floodplain LfSAs are old enough to host prehistoric cultural deposits, but the thickness of the these sediment assemblages remains unexplored.

9 Distribution of Known Prehistoric Cultural Deposits

Mapping of landform sediment assemblages and enhancement of the model of landscape evolution of the mapped project area intentionally is conducted without reference to the distribution of temporally diagnostic cultural artifacts because the artifacts serve as one independent check on the age of different landscape components. The age estimates of a given landform sediment assemblage ought to be no younger than the age of the oldest cultural artifacts that are found on that landform. At this level of analysis, factors such as cultural curation of older artifacts by younger occupants are not considered, and the analysis is subject to the limitations of the site database. "Sites" are located by centroids in the GIS, so site boundaries could skew the location of a centroid into a neighboring LfSA. Apparent discrepancies are noted here for future consideration and potential modification of the model. Also presented are some general observations on the distribution of prehistoric cultural deposits for different cultural periods.

Nearly 400 prehistoric archaeological sites are recorded in that part of the project area mapped with landform sediment assemblages. Many more sites occur within the project limits but beyond the mapped boundaries (e.g., bluff tops), and are considered no further. For the purposes of this discussion, "site" is used in the traditional sense as typically defined during an archaeological survey, although we tend to take a more distributional approach to artifact scatters (cultural deposits) until "site" limits are proven to be cultural rather than geological in origin. The exception to this definition of "site" is that each cultural component (tradition) is considered a "site," although more than one tradition may be represented at a single specific geographic location.

Approximately 80 percent of prehistoric "sites" yielded artifacts or stylistic characteristics that allow some sense of "site" age within the mapped area. Only one site is assigned to the Paleoindian period. The remainder of sites breakdown as follows: Archaic, 5.2 percent; Woodland, 76.0 percent; Mississippian, 10.6 percent; and, Oneota, 7.6 percent. The Paleoindian site occurs on the south-facing colluvial slope (MC2) atop a high terrace in the mouth of the Whitewater River Valley. Multiple cultural components are represented at this locale, so younger occupants could have curated Paleoindian material.

Seventeen cultural deposits have Archaic affiliations. Sites are distributed in the UMV from above the Vermillion Valley mouth to well downstream of the Whitewater valley mouth, with several additional sites in the lower reach of the Cannon Valley, one in the mouth of the Whitewater Valley, and one in the middle meandering bedrock valley reach of the Middle Fork Zumbro River. In the UMV, ten sites are associated with either the Outwash Terrace, Catastrophic Flood, or Valley Terrace landscape, all relatively high valley landscape positions whether along the valley wall or out in the central part of the valley. Five sites are associated with the Valley Margin Landscape. One site occurs on an older colluvial slope in the mouth of the Whitewater Valley. The remaining Valley Margin sites occur on alluvial fans. Two are on the same relict alluvial fan, deposited on a terrace by a tributary of the Cannon River. One is at the mouth of a small tributary, only two meters from a catastrophic flood terrace scarp. The remaining fan site is the LaMoille Rockshelter. In this latter case, the site name suggests the centroid is apparently displaced from a nearby catastrophic flood terrace margin in which the rock shelter is likely exposed. Of the two remaining sites, one formerly was on what was mapped as a segment of an island-braided bar that was destroyed by excavation of a small harbor on the Mississippi River. In the Mississippi River model, this LfSA would seem too young for an Archaic site. The other site has a centroid that is located in one of the Mississippi River pools, about 20 m from the modern bank. It is possible that the site was originally recorded at a low water stage. Both of these sites are close to one another, one on either side of the Wells Creek alluvial fan near Old Frontenac.

A little over three-quarters of the sites have Woodland affiliations. Of this group of sites, a little over half occur on the Catastrophic Flood landscape. The Glaciofluvial landscape has about 18 percent of the sites and the Valley Terrace landscape has about 8 percent. These surfaces, and probably a large degree of their surficial modifications (i.e. local eolian accumulations; alluvial fans on terraces) were established well before the Woodland Period. Therefore, the abundance of Woodland sites in these landscapes is not unexpected. Eight percent of Woodland sites occur in the Valley Margin landscape. Seven sites occur on alluvial fans, and four sites on colluvial slopes. Models of more or less region-wide synchronous alluvial fan evolution in the Midwest (Bettis 2003, Hajic 1990b) suggest the surfaces of fans with perennial streams stabilized during the Woodland period as creeks incised their fans. This has yet to be demonstrated in the UMV project reach, but the presence of several Woodland sites on fan surfaces tends to be in line with these models. The centroid of one of these fans sites, the Early Woodland New Albin Mounds, falls in an older paleomeander belt (MMB6 LfSA) of the Winnebago Creek alluvial fan. The temporally-related alluvial fan lobe (MAF6 LfSA) surrounds the paleomeander belt. The presence of Early Woodland mounds on the Winnebago Creek fan suggests the Mississippi River migrated eastward from the western valley wall in the farthest downstream project area flood basin prior to the Early Woodland period.

Nearly 13 percent of Woodland sites occur in the Floodplain LfSA in the Mississippi Valley and its tributaries. About a third of the sites in the Floodplain Landscape are associated with natural levees of four different generations. Six sites are located on the youngest generation of levees (FNLO1), interpreted here to have a substantial sediment increment that is Historic in age along the Mississippi River. Only two of these sites are associated with the most recent positions of the Mississippi River. If in place, the material suggests at least some antiquity to this particular natural levee reach. However, other reaches of levee must be Historic in age based on the channel location on Historic maps. Thirteen Woodland sites, mostly in tributary valleys, are associated with five flood basin LfSAs and one meander belt. Two of these sites are mapped on the FFWO LfSA, the floodplain type that exhibits the most robust (least buried) point bar morphology. In most cases, this LfSA would be considered too young to host intact Woodland cultural deposits. One of the sites on a FFWO LfSA is only three meters from a segment of the FFXOB LfSA with a more muted point bar morphology, as would be more reasonably expected for a surface site of Woodland age. The other occurs at the mouth of Trout Brook in the Zumbro River valley, and perhaps may involve redeposited cultural material. Two Woodland sites occurred on the island-braided floodplain, but were removed during dredging operations. Five Woodland sites occur on spits protruding into Lake Pepin.

A problem common to all but one of the Floodplain Landscape LfSAs is that they have been mapped as having a veneer of "Type O" floodplain overbank deposits. Although the age of the

"Type O" overbank veneer is not part of its definition, upon examination it is expected to prove to be Historic in age in nearly all cases. The fact that Woodland sites are occurring on floodplain LfSAs mapped with the "Type O" veneer suggests that the "Type O" veneer is perhaps less consistently present than mapping suggests, particularly in the tributaries, and on what are mapped as spits. Overall in the Mississippi Valley, *surface* Woodland sites in the floodplain landscape are rare given the vast area of floodplain, and the "Type O" overbank veneer is likely more consistently present. It is possible, and perhaps even likely, that the majority of sites of Woodland and possibly Archaic age in the Floodplain landscape are buried at depth. Two site centroids occur in water bodies, suggesting there is some issue of recordation, context, or centroid location rather than mapping. One is in the Mississippi River, 21 m from the modern riverbank. The second is the Michaud–Koukal Mounds, the centroid of which is located in one of the lock and dam pools.

There are 35 known Mississippian sites. Twenty-one are located on the Catastrophic Flood landscape, six in the Glaciofluvial, three in the Valley Terrace, three on fans in the Valley Margin landscape, and two in the Floodplain landscape. Of the sites in the Floodplain landscape, one is on an older segment of floodplain that lacks a "Type O" overbank veneer, and the other is on a spit. Mississippian sites are focused along the lowest-middle, and lower reaches of the Cannon Valley, and the southern end of the nearby Prairie Island. Several sites occur down-valley in the Mississippi Valley, but upstream of the mouth of the Zumbro Valley, and a couple upvalley on the southern end of Lower Grey Cloud Island. No Mississippian sites are temporally discordant with the LfSA mapping.

Of the known 25 Oneota sites, 11 occur in the Catastrophic Flood landscape, eight in the Glaciofluvial, one in the Valley Terrace, four on fans in the Valley Margin, and one on an older segment in the Floodplain landscape. There are loose clusters of Oneota sites around Spring Lake in the Mississippi Valley upstream of the Vermillion Valley mouth, and along the lower reach of the Cannon Valley and the southern end of the nearby Prairie Island. More isolated occurrences are found to the south, mostly in the mouths of coulees. No Oneota sites are temporally discordant with the LfSA mapping.

10 Conclusions

The Upper Mississippi Valley reach of the project area is dominated by the floodplain, glaciofluvial and outwash landscapes. At least two episodes of catastrophic flooding, the larger during the Late Wisconsin, the younger and smaller around the Pleistocene–Holocene transition, incised pre-existing outwash plains and probably the bedrock valley floor, notching a series of descending terraces into the outwash sediment assemblages, creating catastrophic flood landforms, and setting the stage for Holocene landscape evolution in the valley. During the earliest Holocene, the Mississippi River probably ran in the catastrophic flood gorge. Bedrock strath terraces along the gorge were moist environments fed by groundwater. As alluvial fans built out into the gorge, Lake Pepin, and likely other valley lakes, formed. Valley and lake margin environments would have been important prehistorically, particularly during the early Holocene. Lake levels at different times throughout the Holocene remain undocumented. As the lake(s) filled, the Mississippi River entered the lake, prograding down through the uppermost part of the project area during the late Holocene. Below the downstream end of Lake Pepin, the Mississippi River established a gently meandering pattern creating distinct flood basins. Between the progradation and overbank sedimentation of the Mississippi River, and the activity of tributary creeks, a varied floodplain evolved with increasingly suitable depositional environments for prehistoric occupation at some unknown depth below the modern floodplain. The prehistoric floodplain mosaic was mostly buried by changes wrought by installation of locks and dams, although more remote floodplain areas and those on low-lying catastrophic flood LfSAs remain less affected.

Outwash terraces above the impact of catastrophic flooding are old enough to have cultural deposits of pre-Paleoindian and younger cultural periods on this surface with little geologic potential for buried cultural deposits. Discontinuous eolian deposits, and possibly thin loess, can locally bury patches of the terraces and any associated prehistoric cultural deposits. The same is true for terrace levels cut by the older catastrophic flood but unaffected by the younger one. Surfaces altered by the younger flood can host surface cultural deposits no older than the Late Paleoindian period. Lowest catastrophic flood surfaces are buried, sometimes deeply, by lake, floodplain, and alluvial fan deposits. There is the potential for deep burial of any associated cultural material.

The Mississippi River floodplain overall is Historic in age. There are floodplain surfaces that pre-date the Historic period, but the sense is that the bulk of a prehistoric floodplain is shallowly buried and ill-defined at best. Prehistoric floodplain elements not associated directly with the lowest terraces are likely to host deposits of only the youngest prehistoric cultural groups. The valley margin environment has a high geologic potential for hosting buried prehistoric cultural deposits, particularly where lowest terrace levels are buried by alluvial fans, and higher terrace levels have a colluvial apron. However, due to swings of the Mississippi River, even some of the larger alluvial fans are likely to be mostly Historic or terminal prehistoric in age.

In tributary valleys, rivers and creeks flow in active meander belts that grade to alluvial fans and in some cases fan deltas at valley mouths. Meander belts are flanked by different generations of floodplain segments. Multiple outwash or valley terraces, particularly in the Vermillion River Valley, however, occupy the bulk of the valley width of the larger tributaries. Downcutting in the UMV during catastrophic flooding undoubtedly played a role in tributary terrace formation as they responded in kind. Pre-Paleoindian, Paleoindian and younger cultural deposits will be on higher terrace surfaces, whereas lower outwash and valley terraces can have Archaic and younger cultural deposits on their surfaces. The age of different floodplain types is unknown, but the distribution of known prehistoric cultural deposits suggest that they are predominantly late Holocene in age, although basal ages will increase with distance away from the rivers, and older cultural deposits are possible beneath floodplains that show fewer alluvial features such as point bars or paleomeanders. The active channel belts are Historic in age, but apparently there is reworking of artifacts from older LfSAs as some debris has been recorded from these active areas.

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Tables

Table 1. Radiocarbon ages from the Mississippi River landform sediment assemblages.

^{14}C Age yr B.P.[a]	Median Probability, Cal yr B.P.	68.3% (1σ) Cal Age Ranges B.P.	95.4% (2σ) Cal Age Ranges B.P.	$\delta^{13}C$ (‰)	Core, Depth Interval (m)	LfSA	Material Dated	Dating Method	Lab Number
>43500	N/A			-24.6 o/oo	10DK-01 15.5 ft	OT15:22	(organic material): acid/alkali/acid	AMS	Beta 279895
1810 +/- 40	1750	1810-1700	1830-1680 1670-1620	-28.1 o/oo	10DK-03 4.0-4.55 ft	OT15:22	(peat): acid/alkali/acid	AMS	Beta 279897
18020 +/- 70	21480	21410-21220	21500-21120	-26.6 o/oo	10DK-03 8.4 ft	OT15:22	(organic sediment): acid washes	AMS	Beta 279898
9770 +/- 50	11200	11230-11180	11250-11150	-24.9 o/oo	10DK-12 29.95-30.30 ft	MAF:22	(organic sediment): acid washes	AMS	Beta 279899
10420 +/- 70	12300	12580-12480 12400-12140	12650-12060	-26.0 o/oo	10GD-02 21.2-21.5 ft	CPCMA>>3; Beneath MC1:22	(wood): acid/alkali/acid	Radiometric	Beta 279900
151.4 +/- 0.6 Modern Carbon	Modern			-28.2 o/oo	10GD-03 12.0-12.1 ft	MAF:22	(wood): acid/alkali/acid	AMS	Beta 279901
18750 +/- 70	22350	22360-22260	22410-22210	-25.4 o/oo	10WN-01 24.75-26.83 ft	VT15:22; Slackwater facies	(plant material): acid/alkali/acid	AMS	Beta 279902
8350 +/- 40	9370	9440-9380 9370-9310	9470-9280	-24.8 o/oo	10GD-02 17.0-17.3 ft	CPCMA>>3; Beneath MC1:22	(plant material): acid/alkali/acid	AMS	Beta 281005

a. The ^{14}C BP ages are calculated on a half-life of 5,568 years and are corrected for isotopic fractionation.
b. Calibration to calendar years was performed with CALIB 5.0 (Stuiver and Reimer, 1993) using calibration dataset intcal04.14c (Reimer et al., 2004).

Table 2: Optically stimulated luminescence (OSL) ages on quartz grains from fluvial sediments, Upper Mississippi Valley for Foth Infrastructure & Environmental, LLC

Sample Number	Depth (m)	Quartz Size (µm)	Laboratory Number	Aliquots	Equivalent Dose (Gray)[a]	U (ppm)[d]	Th (ppm)[d]	K_20 (%)[d]	H_20 (%)	Cosmic Dose (mGray/yr)[e]	Dose Rate (mGray/yr)	OSL Age (yr)[f]
SB-01/10DK-01	2.7-3.4	425-500	UIC2767	30	63.91 ± 5.69[b]	1.0 ± 0.1	3.3 ± 0.1	2.19± 0.02	7.5 ± 3	0.148 ± 0.015	1.80 ± 0.09	35,460 ± 4180
SB-01/10DK-01	18.0.-18.6	150-250	UIC2766	30	258.20 ± 14.11[b]	0.8 ± 0.1	2.8 ± 0.1	1.37 ± 0.01	15 ± 5	0.033 ± 0.003	1.46 ± 0.07	176,540 ± 17,350
SB-02/10DK-02	2.4-3.7	425-500	UIC2755	29	31.41 ± 2.93[b]	0.7 ± 0.1	2.3 ± 0.1	1.24 ± 0.01	30 ± 5	0.148 ± 0.015	1.11 ± 0.06	28,210 ± 3370
SB-03/10DK-03	3.7-4.9	425-500	UIC2663	30	21.21 ± 0.78[c]	1.0 ± 0.1	5.6 ± 0.1	1.51 ± 0.01	30 ± 5	0.130 ± 0.013	1.30 ± 0.06	18,890 ± 1635
SB-04/10DK-04	2.4-3.7	Too Coarse	UIC2760									Undatable
SB-05/10DK-05	2.4-3.7	100-150	UIC2754	30	28.45 ± 1.00[c]	0.6 ± 0.1	1.9 ± 0.1	0.97 ± 0.01	7.5 ± 3	0.148 ± 0.015	1.13 ± 0.06	25,080 ± 1920
SB-05/10DK-05	7.8-7.9	100-150	UIC2764	30	34.09 ± 3.70[c]	0.8 ± 0.1	2.5 ± 0.1	1.31 ± 0.01	30 ± 5	0.082 ± 0.008	1.13 ± 0.06	26,885 ± 3580
SB-06/10DK-06	1.2-2.4	250-355	UIC2756	30	5.10 ± 0.40[b]	0.9 ± 0.1	2.5 ± 0.1	1.16 ± 0.01	7.5 ± 3	0.180 ± 0.018	1.49 ± 0.07	3415 ± 350
SB-07/10DK-07	3.7-4.9	150-250	UIC2759	30	53.65 ± 3.31[b]	0.8 ± 0.1	2.6 ± 0.1	1.21 ± 0.01	15 ± 5	0.130 ± 0.013	1.40 ± 0.07	38,180 ± 3815
SB-08/10DK-08	2.4-3.7	425-500	UIC2749	30	Poor precision	0.7 ± 0.1	2.4 ± 0.1	0.99 ± 0.01	15 ± 5	0.148 ± 0.015	1.11 ± 0.06	Undatable
SB-09/10DK-09	1.2-1.9	425-500	UIC2751	26	29.82 ± 1.09[c]	1.0 ± 0.1	3.2 ± 0.1	1.43 ± 0.01	7.5 ± 3	0.180 ± 0.018	1.69 ± 0.08	17,680 ± 1540
SB-10/10DK-10	1.2-2.4	425-500	UIC2762	30	37.74 ± 3.98[b]	0.7 ± 0.1	2.7 ± 0.1	1.29 ± 0.01	7.5 ± 3	0.180 ± 0.018	1.48 ± 0.07	25,420 ± 3070
SB-10/10DK-10	6.1-7.3	425-500	UIC2761	28	27.09 ± 5.19[c]	0.8 ± 0.1	2.8 ± 0.1	1.16 ± 0.01	15 ± 5	0.096 ± 0.001	1.23 ± 0.06	21,995 ± 4550
SB-12/10DK-12	11.40-11.50	425-500	UIC2750	24	10.06 ± 0.74[b]	1.1 ± 0.1	4.4 ± 0.1	1.92 ± 0.02	15 ± 5	0.059 ± 0.006	1.90 ± 0.09	5300 ± 580
SB-14/10DK-14	8.5-9.5	Too Coarse	UIC2765									Undatable

[a]150 to 250 µm quartz fraction analyzed under blue-light excitation (470 ± 20 nm) by single aliquot regeneration protocols (Murray and Wintle, 2003).
[b]Ages calculated using the central age model of Galbraith et al. (1999).
[c]Ages calculated using the minimum age model of Galbraith et al. (1999).
[d]U, Th and K_20 content analyzed by inductively coupled plasma-mass spectrometry analyzed by Activation Laboratory LTD, Ontario, Canada.
[e]From Presott and Hutton (1994).
[f]All errors are at 1 sigma and ages from the reference year AD 2009.

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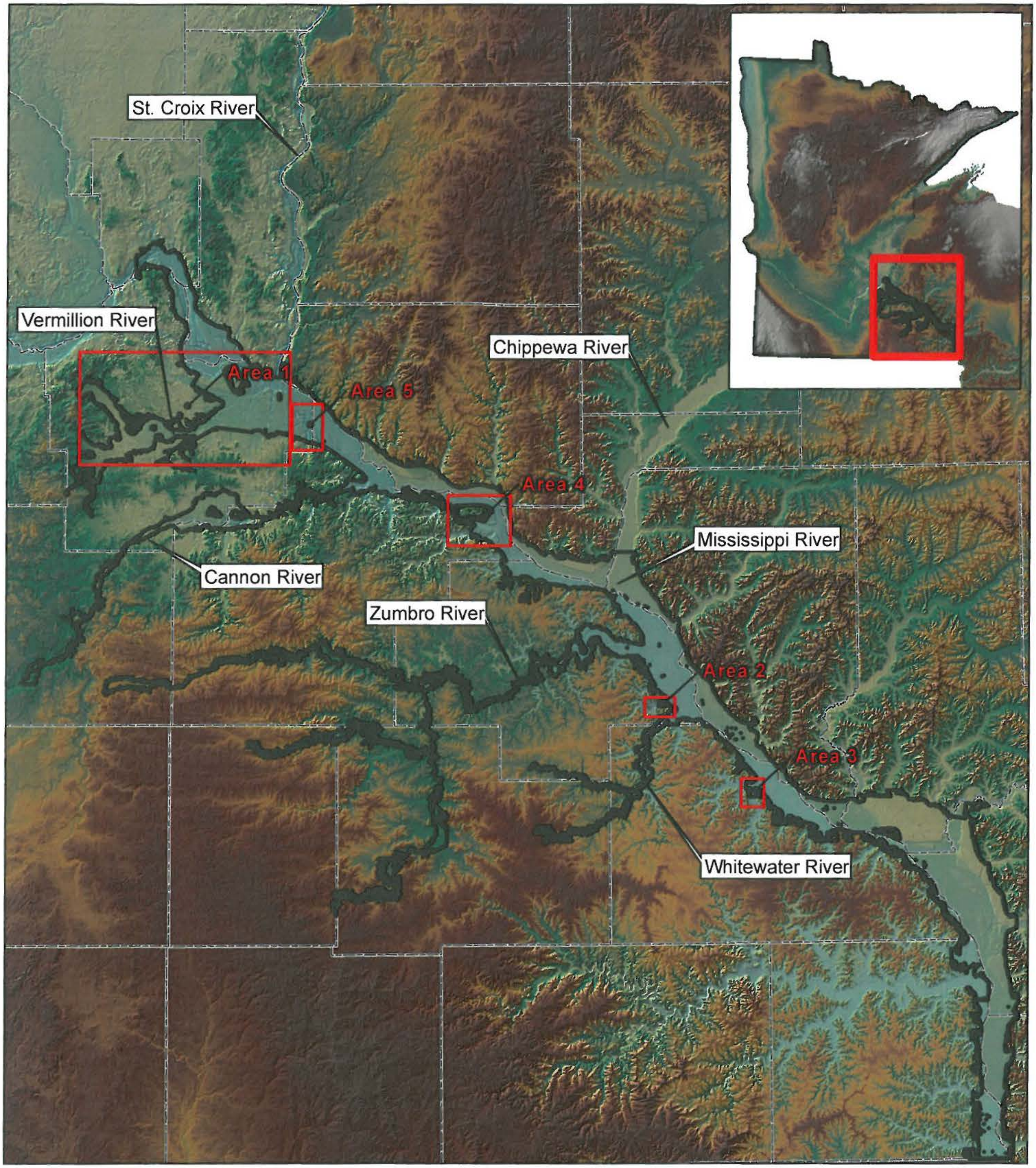
Figures



NOTES

Basemap Source: USGS 10-Meter Digital Elevation Model
Projection: UTM Zone 15 North
Horizontal Datum: NAD83
Units: Meters

LEGEND

Mississippi-Zumbro LfSA Extent
Counties

N

MINNESOTA DEPARTMENT OF TRANSPORTATION

FIGURE 1
Mississippi-Zumbro Project Location and Areas with Cores and Cross-Sections

Scale: 0 10 20 Kilometers	Date: SEPTEMBER, 2011
Prepared by: JJW1	Project No: 07M095

Foth
Foth Infrastructure & Environment, LLC

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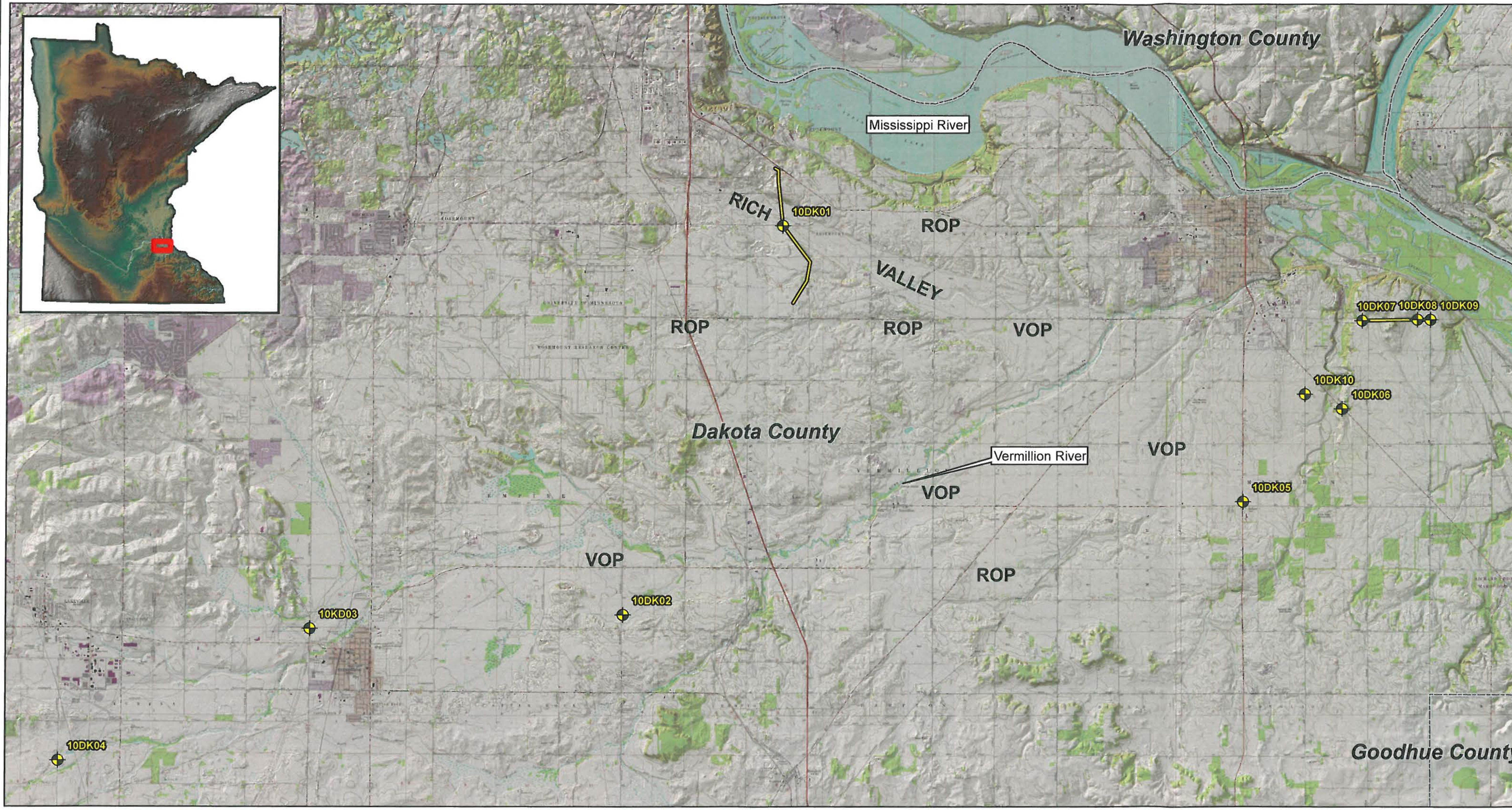

NOTES

Basemap Source: USGS 7.5' Minute Series Topographic Quadrangles
Projection: UTM Zone 15 North
Horizontal Datum: NAD83
Units: Meters

LEGEND

Sediment / Soil Cores
Cross-Sections
ROP - Rosemount Outwash Plain (OT20)
VOP - Vermillion Outwash Plain (OT15)

N

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FIGURE 2
Area 1 Core Locations
and Cross-Section Lines

Scale: 0 1 2 Kilometers
Date: SEPTEMBER, 2011
Prepared by: JJW1
Project No: 07M095

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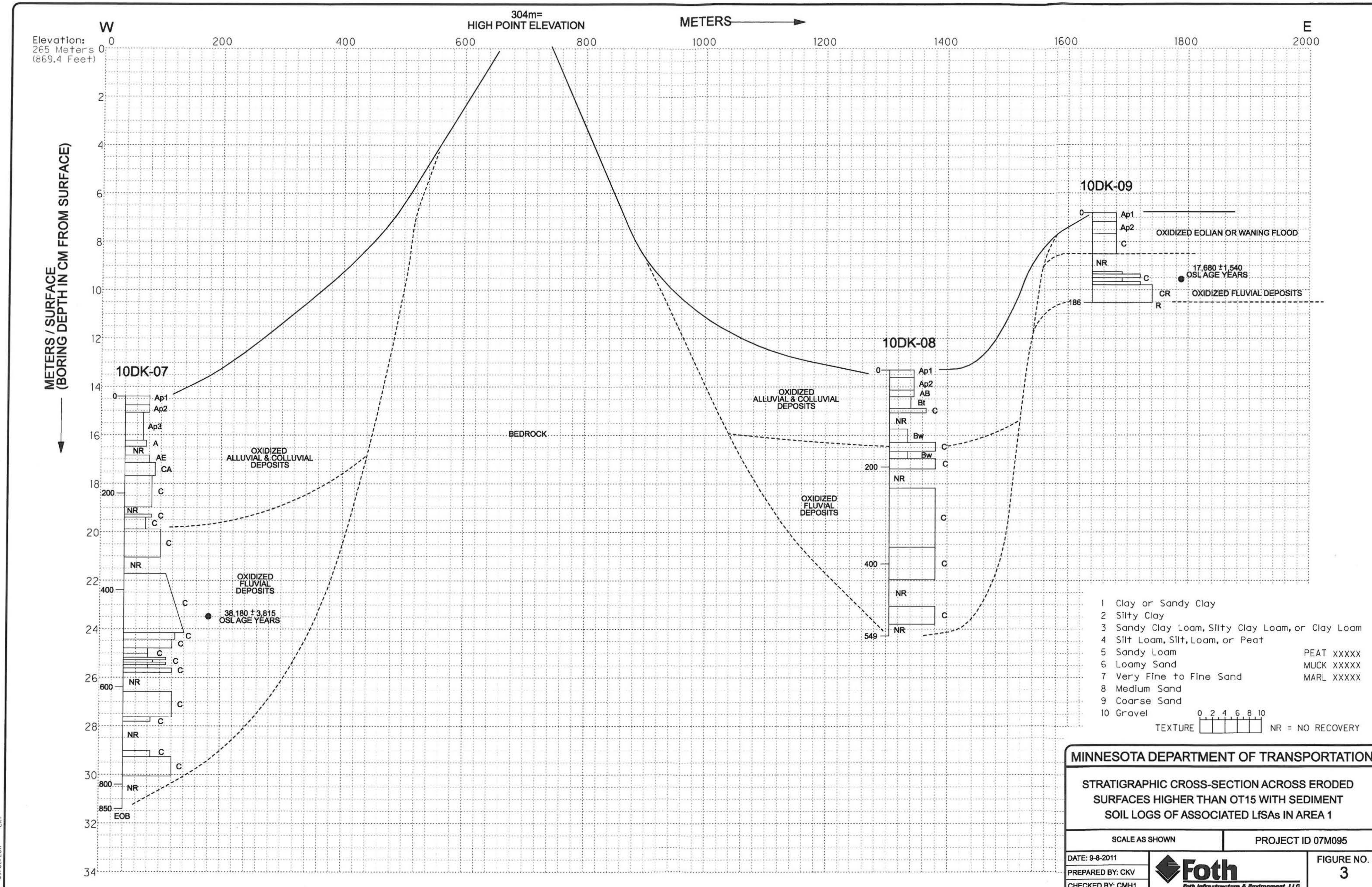
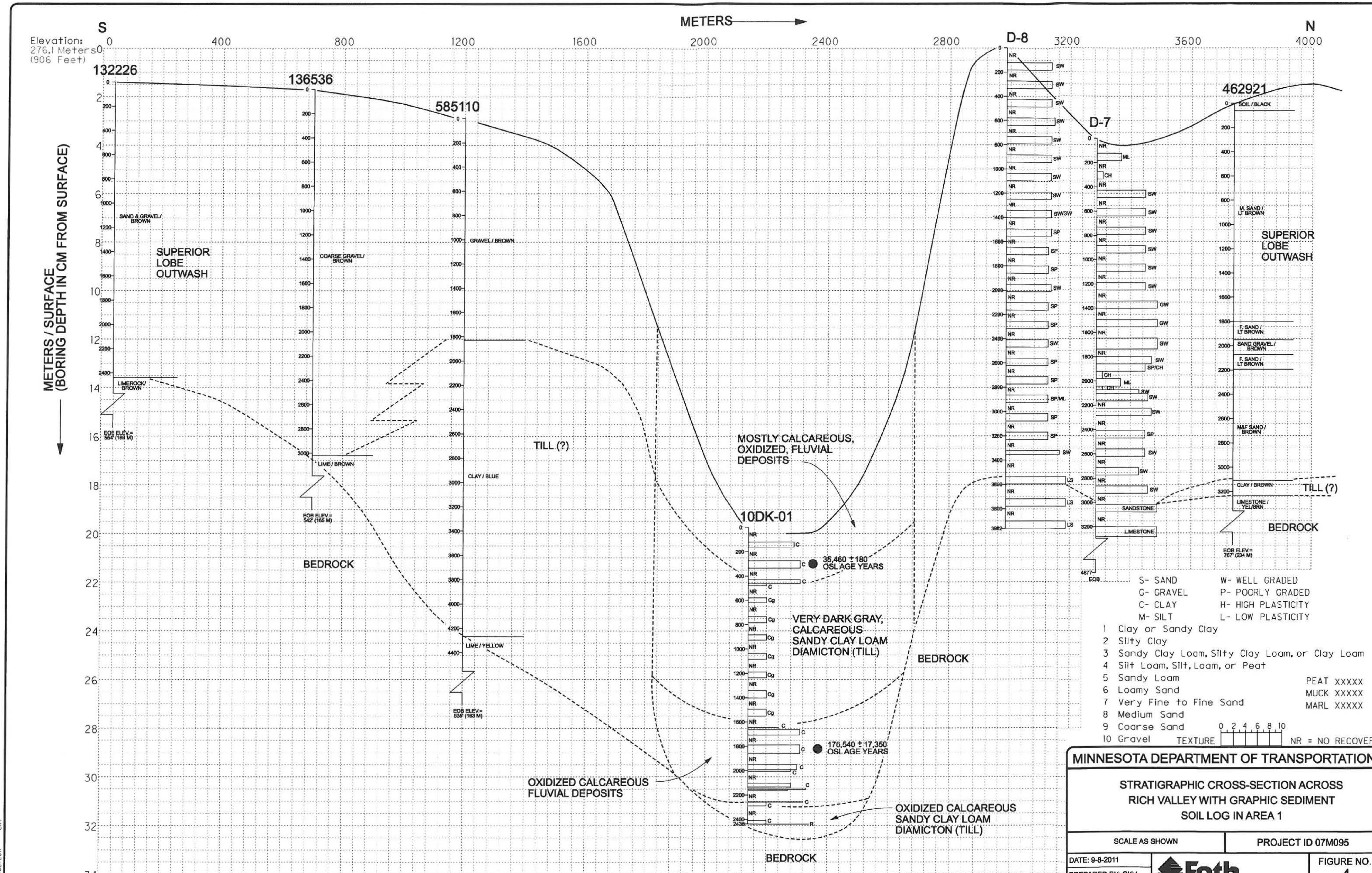


304m=
HIGH POINT ELEVATION
METERS
W
E
Elevation: 265 Meters (869.4 Feet)
0 200 400 600 800 1000 1200 1400 1600 1800 2000
METERS / SURFACE (BORING DEPTH IN CM FROM SURFACE)
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34
10DK-07
Ap1 Ap2 Ap3 A NR AE CA C NR C C C NR C C C C C C NR C C NR C C NR EOB
0 200 400 600 800 850
OXIDIZED ALLUVIAL & COLLUVIAL DEPOSITS
OXIDIZED FLUVIAL DEPOSITS
38,180 ± 3,815 OSL AGE YEARS
BEDROCK
10DK-08
Ap1 Ap2 AB Bt C NR Bw C Bw C NR C C NR C NR
0 200 400 549
OXIDIZED ALLUVIAL & COLLUVIAL DEPOSITS
OXIDIZED FLUVIAL DEPOSITS
10DK-09
Ap1 Ap2 C NR C CR R
0 186
OXIDIZED EOLIAN OR WANING FLOOD
17,680 ± 1,540 OSL AGE YEARS
OXIDIZED FLUVIAL DEPOSITS
1 Clay or Sandy Clay
2 Silty Clay
3 Sandy Clay Loam, Silty Clay Loam, or Clay Loam
4 Silt Loam, Silt, Loam, or Peat
5 Sandy Loam
6 Loamy Sand
7 Very Fine to Fine Sand
8 Medium Sand
9 Coarse Sand
10 Gravel
PEAT XXXXX
MUCK XXXXX
MARL XXXXX
TEXTURE 0 2 4 6 8 10
NR = NO RECOVERY
MINNESOTA DEPARTMENT OF TRANSPORTATION
STRATIGRAPHIC CROSS-SECTION ACROSS ERODED SURFACES HIGHER THAN OT15 WITH SEDIMENT SOIL LOGS OF ASSOCIATED LfSAs IN AREA 1
SCALE AS SHOWN
PROJECT ID 07M095
DATE: 9-8-2011
PREPARED BY: CKV
CHECKED BY: CMH1
Foth
Foth Infrastructure & Environment, LLC
FIGURE NO. 3



MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHIC CROSS-SECTION ACROSS RICH VALLEY WITH GRAPHIC SEDIMENT SOIL LOG IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095
DATE: 9-8-2011 / PREPARED BY: CKV / CHECKED BY: CMH1	FIGURE NO. 4

Foth Infrastructure & Environment, LLC

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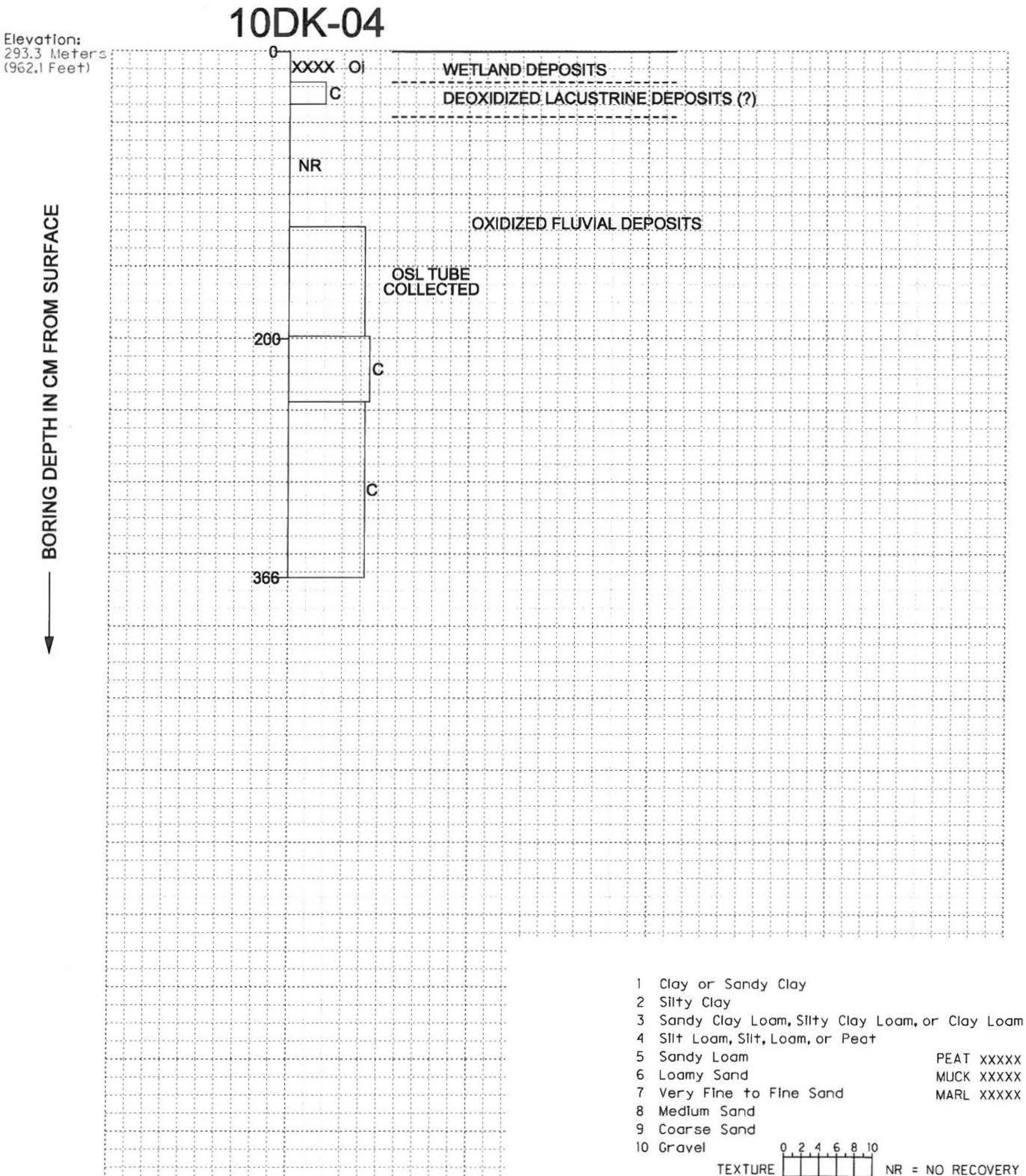

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT
SOIL LOGS OF THE OT15 LfSA IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO. 5A

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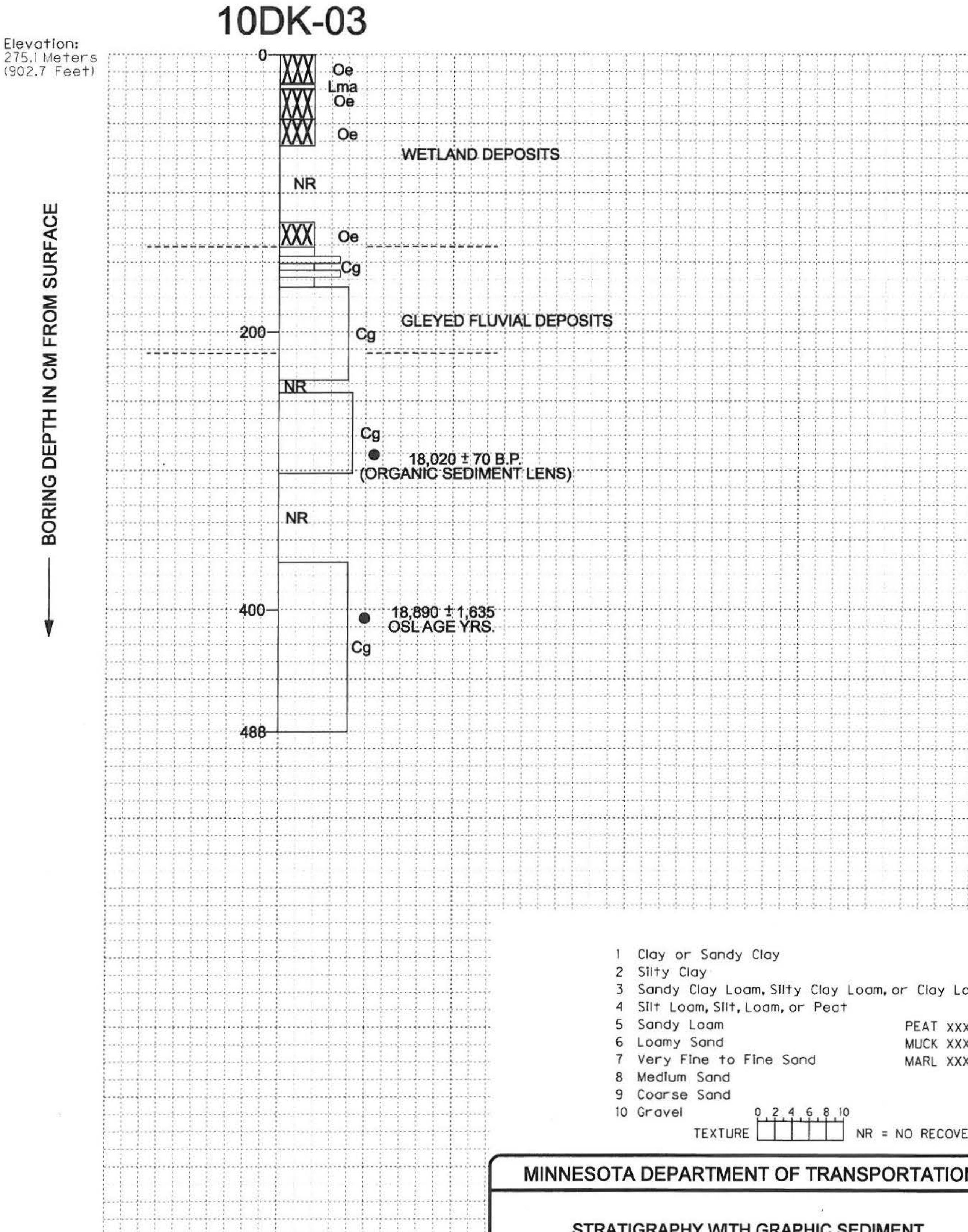

1 Clay or Sandy Clay
2 Silty Clay
3 Sandy Clay Loam, Silty Clay Loam, or Clay Loam
4 Silt Loam, Silt, Loam, or Peat
5 Sandy Loam
6 Loamy Sand
7 Very Fine to Fine Sand
8 Medium Sand
9 Coarse Sand
10 Gravel

PEAT XXXXX
MUCK XXXXX
MARL XXXXX

TEXTURE 0 2 4 6 8 10

NR = NO RECOVERY

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT SOIL LOGS OF THE OT15 LfSA IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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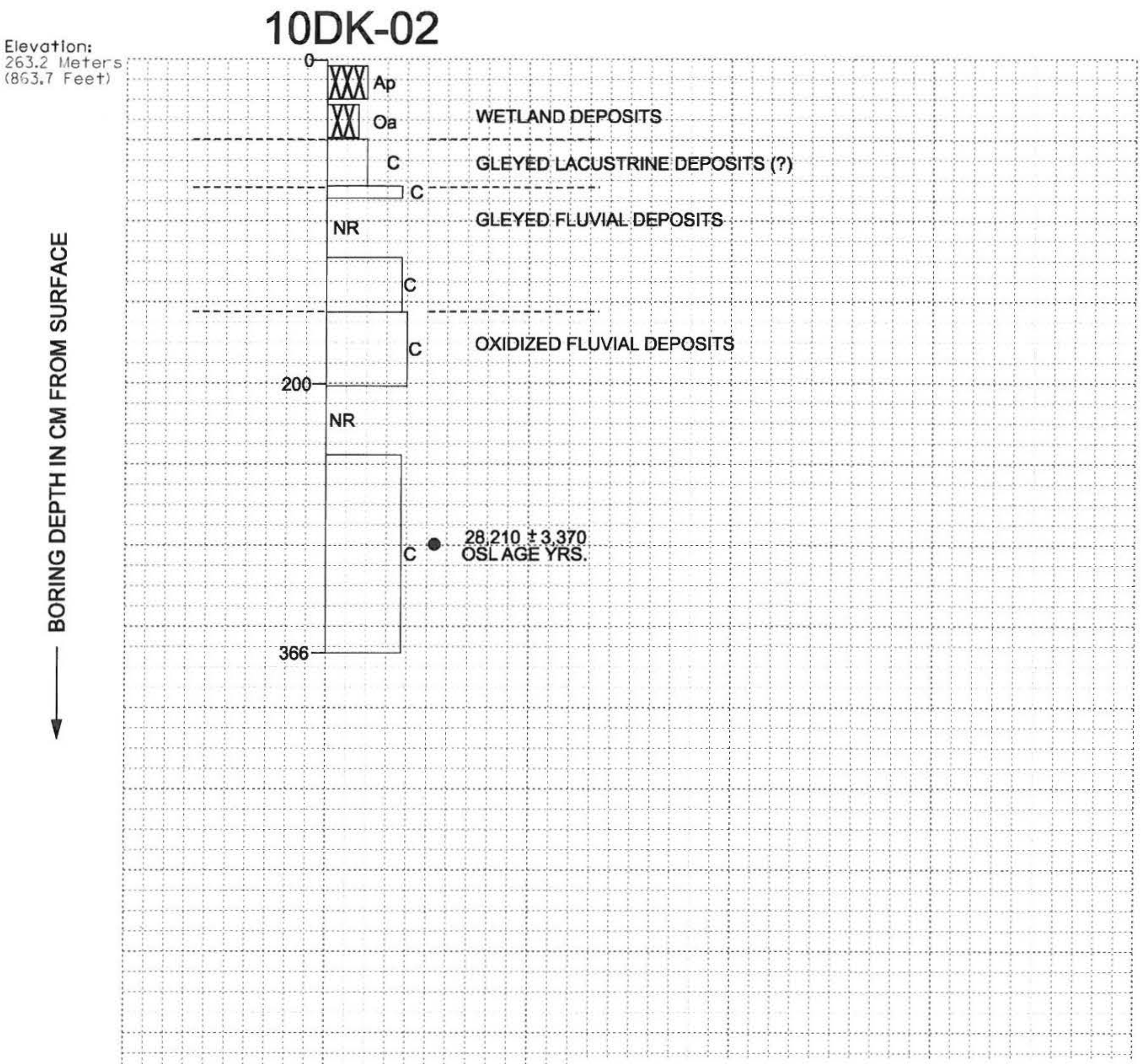
Foth Infrastructure & Environment, LLC

FIGURE NO.
5B

09/08/2011 11:33:54 AM ckv x:\ms\ie\2011\11M018\cad\exhibits and figures\11M018_cores.dgn



1 Clay or Sandy Clay
2 Silty Clay
3 Sandy Clay Loam, Silty Clay Loam, or Clay Loam
4 Silt Loam, Silt, Loam, or Peat
5 Sandy Loam
6 Loamy Sand
7 Very Fine to Fine Sand
8 Medium Sand
9 Coarse Sand
10 Gravel

PEAT XXXXX
MUCK XXXXX
MARL XXXXX

TEXTURE 0 2 4 6 8 10

NR = NO RECOVERY

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT
SOIL LOGS OF THE OT15 LfSA IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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Foth Infrastructure & Environment, LLC

FIGURE NO.
5C

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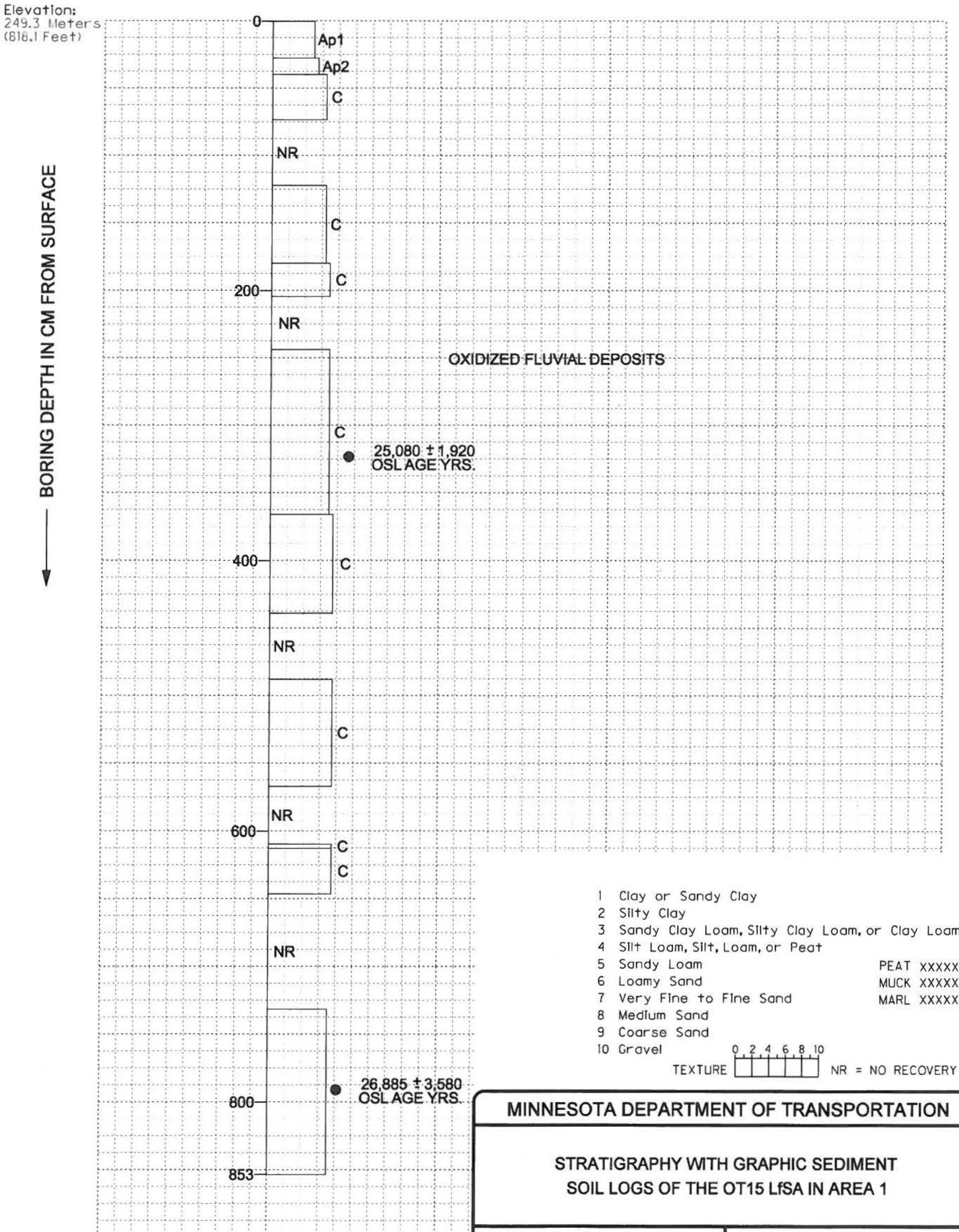
10DK-05



MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT
SOIL LOGS OF THE OT15 LfSA IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

Foth Infrastructure & Environment, LLC

FIGURE NO.
5D

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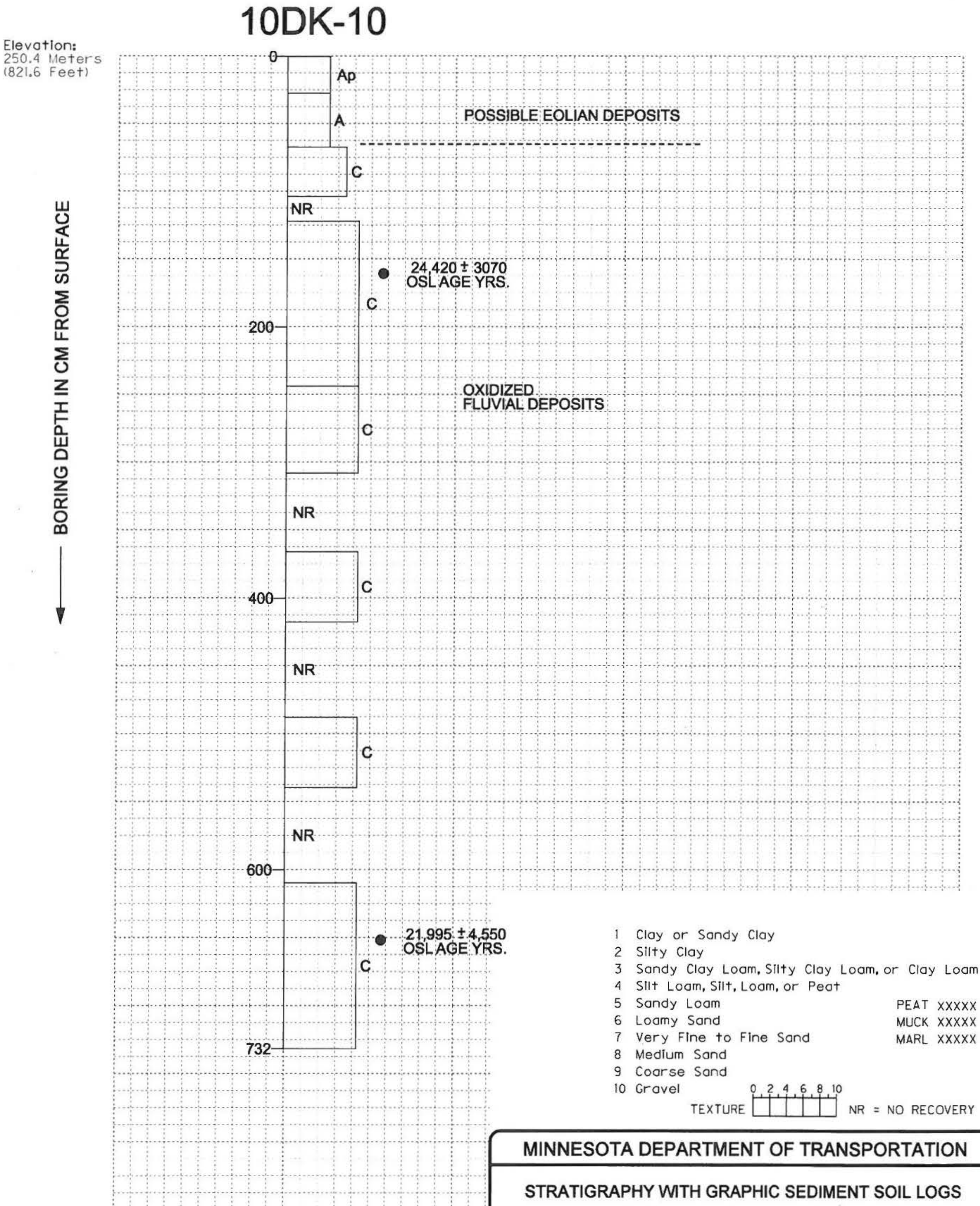

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT SOIL LOGS OF LfSAS IMMEDIATELY LOWER THAN THE OT15 LfSA IN AREA 1

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO.
6A

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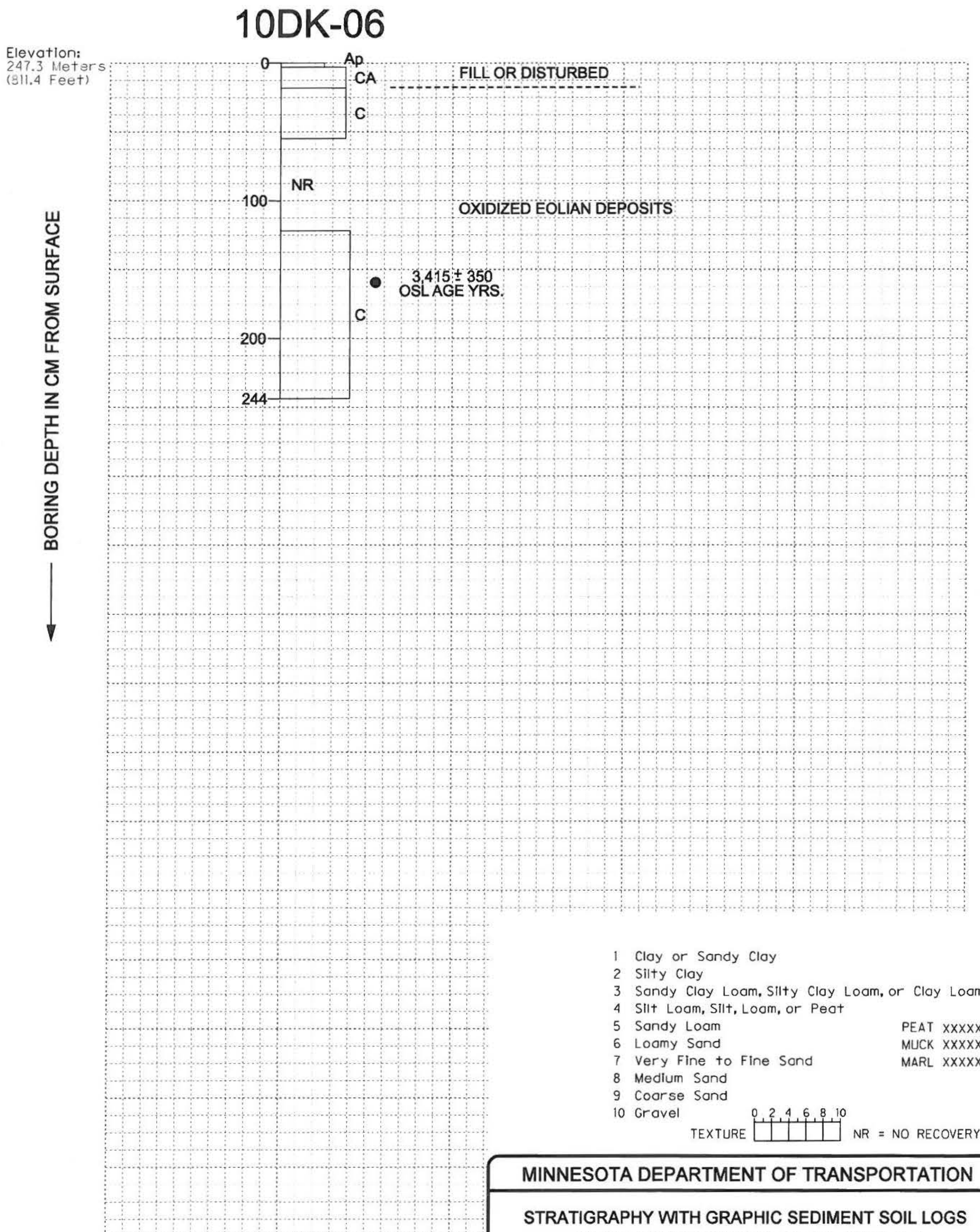

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT SOIL LOGS OF LfSAS IMMEDIATELY LOWER THAN THE OT15 LfSA IN AREA 1

SCALE AS SHOWN

PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO. 6B

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NOTES

Basemap Source: USGS 7.5' Minute Series Topographic Quadrangles
Projection: UTM Zone 15 North
Horzontal Datum: NAD83
Units: Meters

LEGEND

Sediment / Soil Cores

N

Foth
Foth Infrastructure & Environment, LLC

MINNESOTA DEPARTMENT OF TRANSPORTATION

FIGURE 7
Area 2 Core Location

Scale: 0 0.25 0.5 Kilometers	Date: SEPTEMBER, 2011
Prepared by: JJW1	Project No: 07M095

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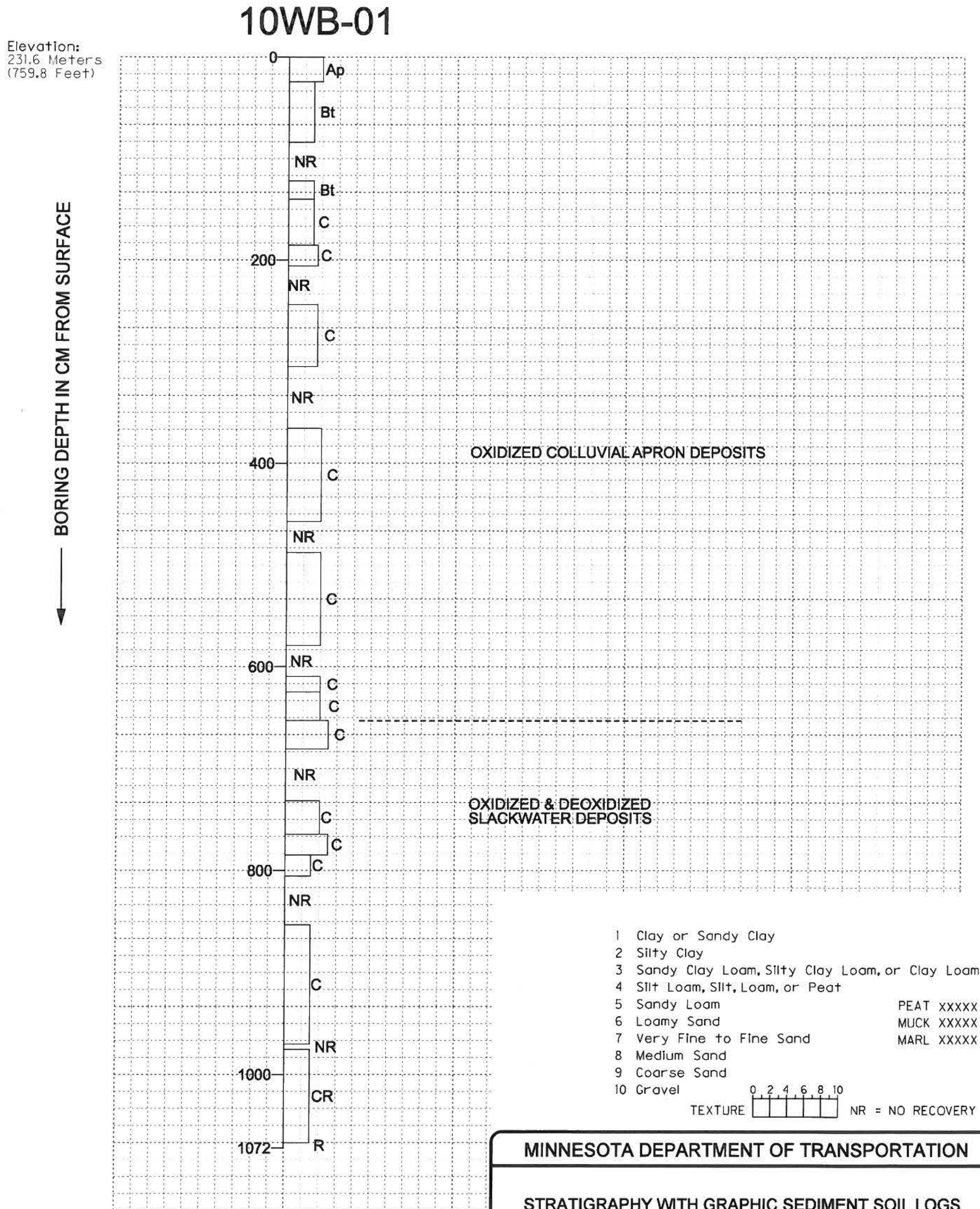

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT SOIL LOGS OF THE MAIN SLACKWATER TERRACE IN AREA 2

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

Foth Infrastructure & Environment, LLC

FIGURE NO.
8

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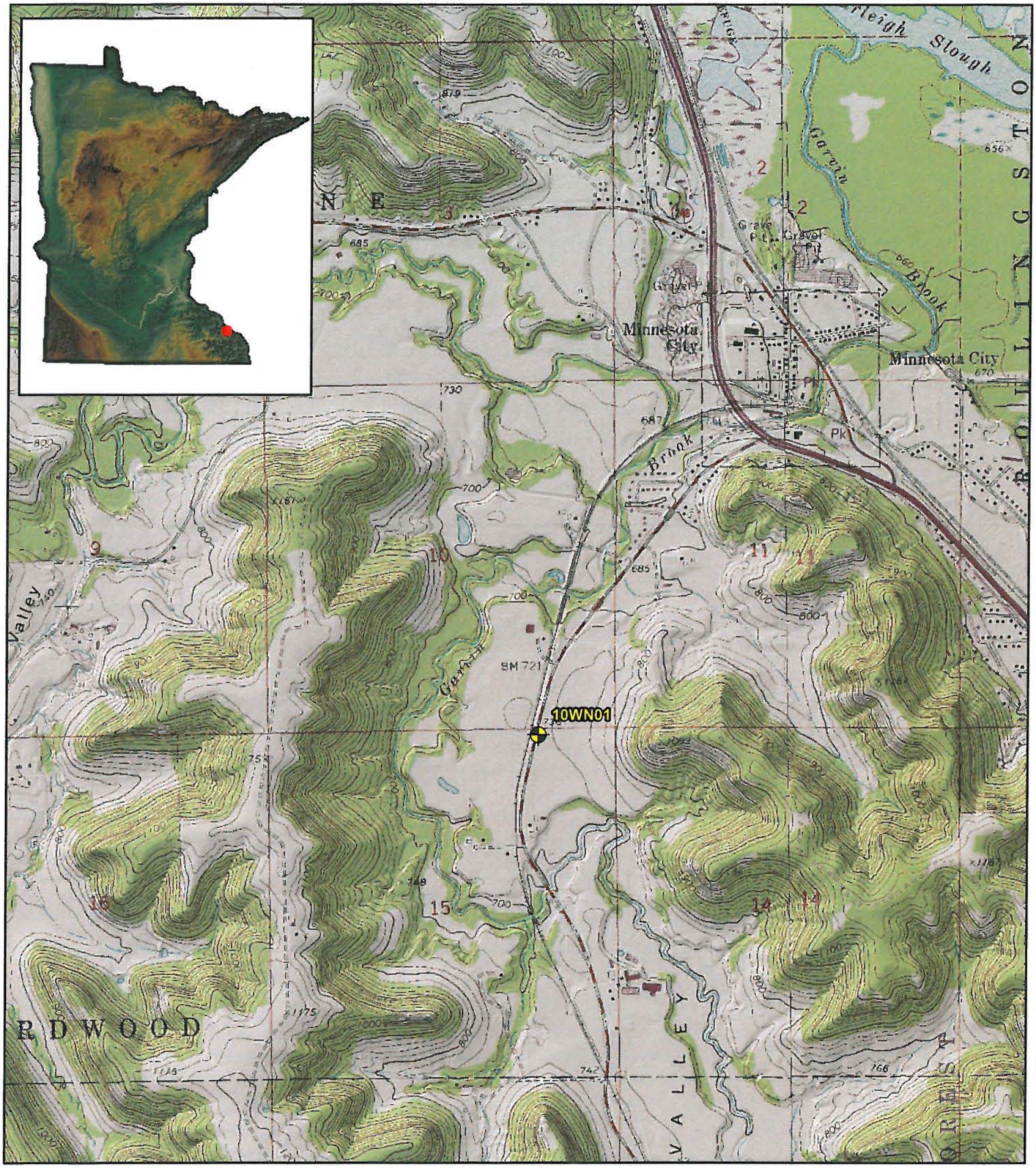

NOTES

Basemap Source: USGS 7.5' Minute Series Topographic Quadrangles
Projection: UTM Zone 15 North
Horzontal Datum: NAD83
Units: Meters

LEGEND

Sediment / Soil Cores

N

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Foth Infrastructure & Environment, LLC

MINNESOTA DEPARTMENT OF TRANSPORTATION

FIGURE 9
Area 3 Core Location

Scale: 0 0.25 0.5 Kilometers	Date: SEPTEMBER, 2011
Prepared by: JJW1	Project No: 07M095

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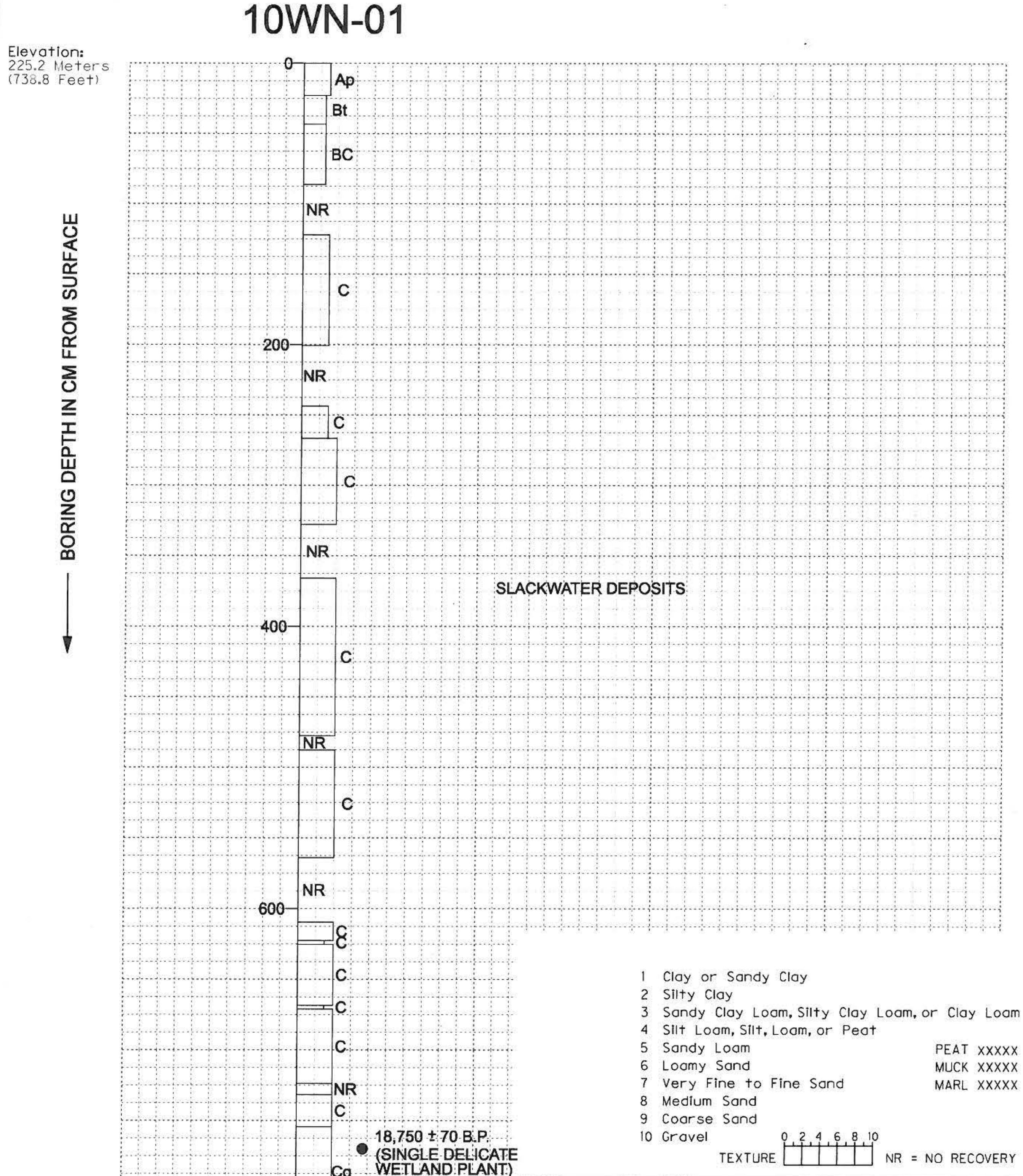

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY WITH GRAPHIC SEDIMENT SOIL LOG OF THE MAIN SLACKWATER TERRACE IN AREA 3

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO.
10

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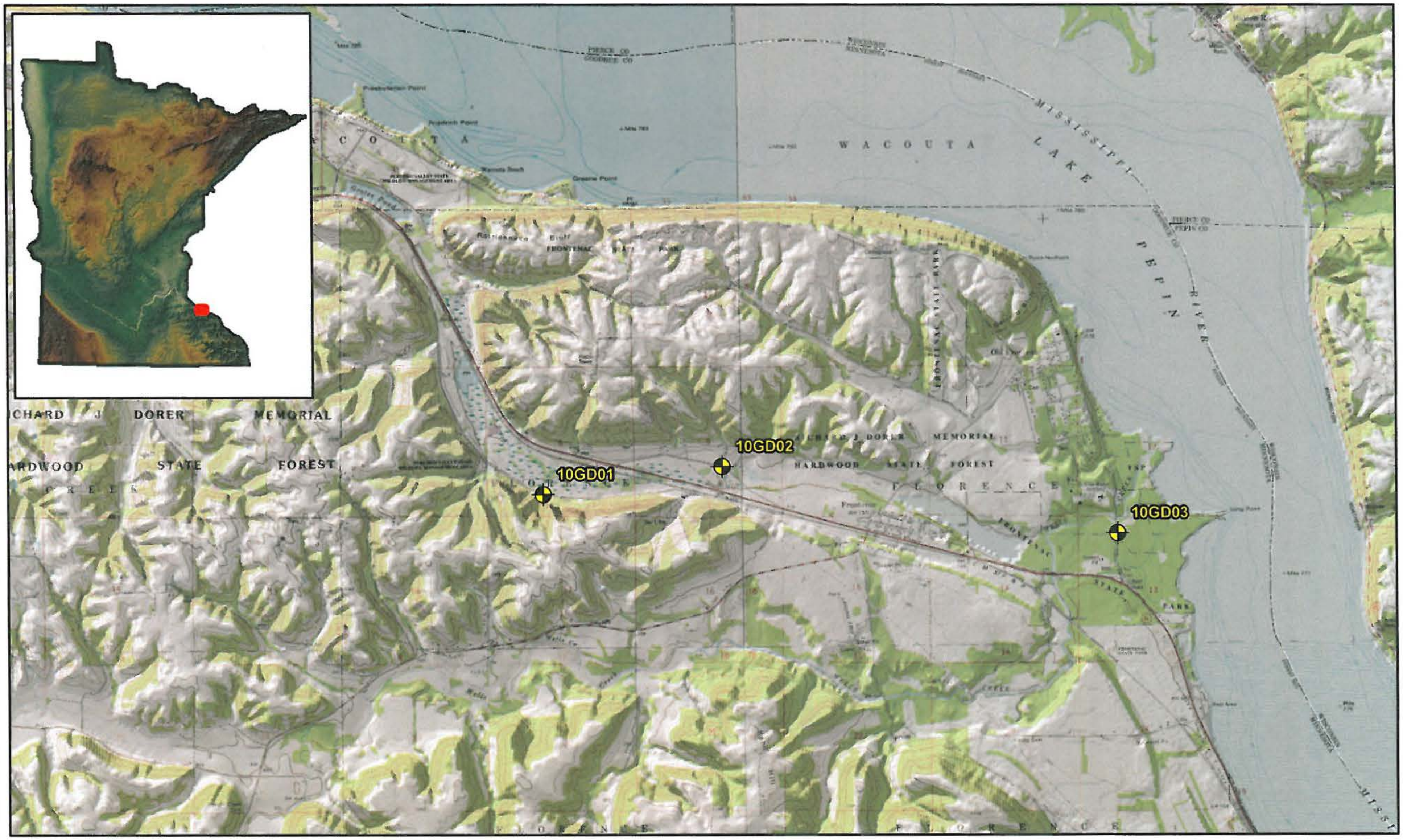

NOTES

Basemap Source: USGS 7.5' Minute Series Topographic Quadrangles
Projection: UTM Zone 15 North
Horzontal Datum: NAD83
Units: Meters

LEGEND

Sediment / Soil Cores

N

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FIGURE11
Area 4 Core Locations

Scale: 0 0.5 1 Kilometers	Date: SEPTEMBER, 2011
Prepared by: JJW1	Project No: 07M095

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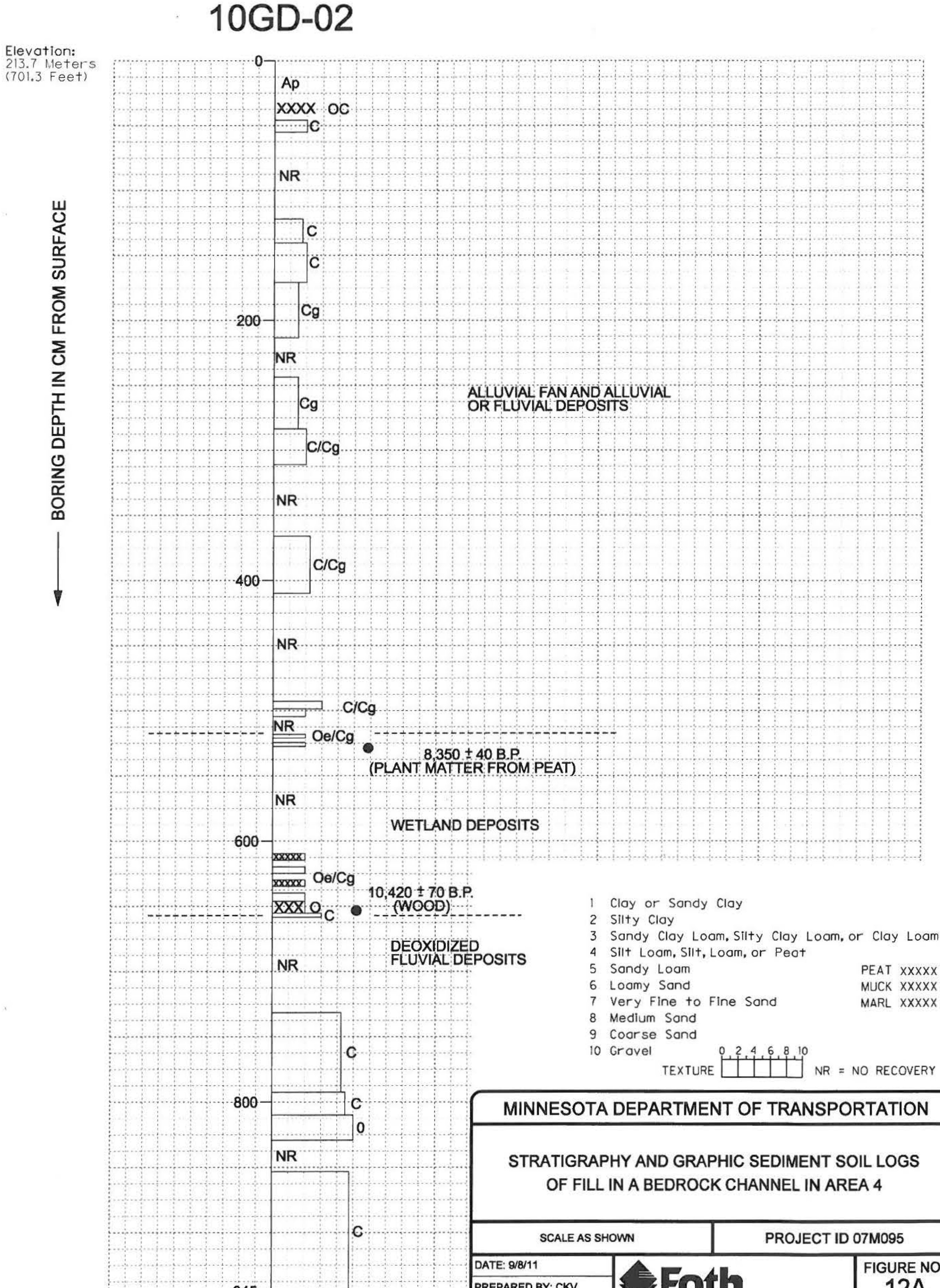

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY AND GRAPHIC SEDIMENT SOIL LOGS OF FILL IN A BEDROCK CHANNEL IN AREA 4

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11	Foth Infrastructure & Environment, LLC	FIGURE NO. 12A
PREPARED BY: CKV		
CHECKED BY: CMH1		

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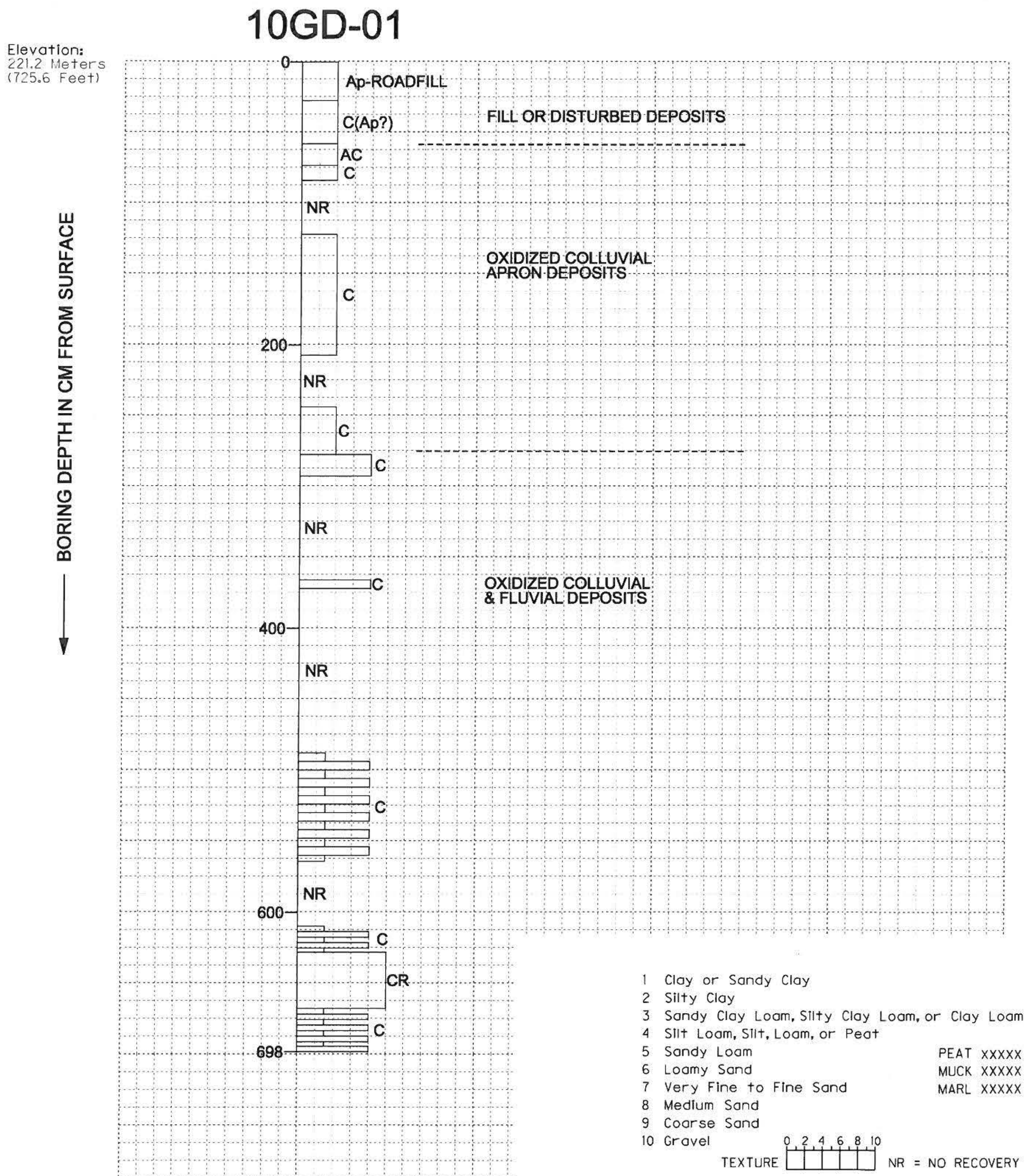

MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY AND GRAPHIC SEDIMENT SOIL LOGS OF FILL IN A BEDROCK CHANNEL IN AREA 4

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO. 12B

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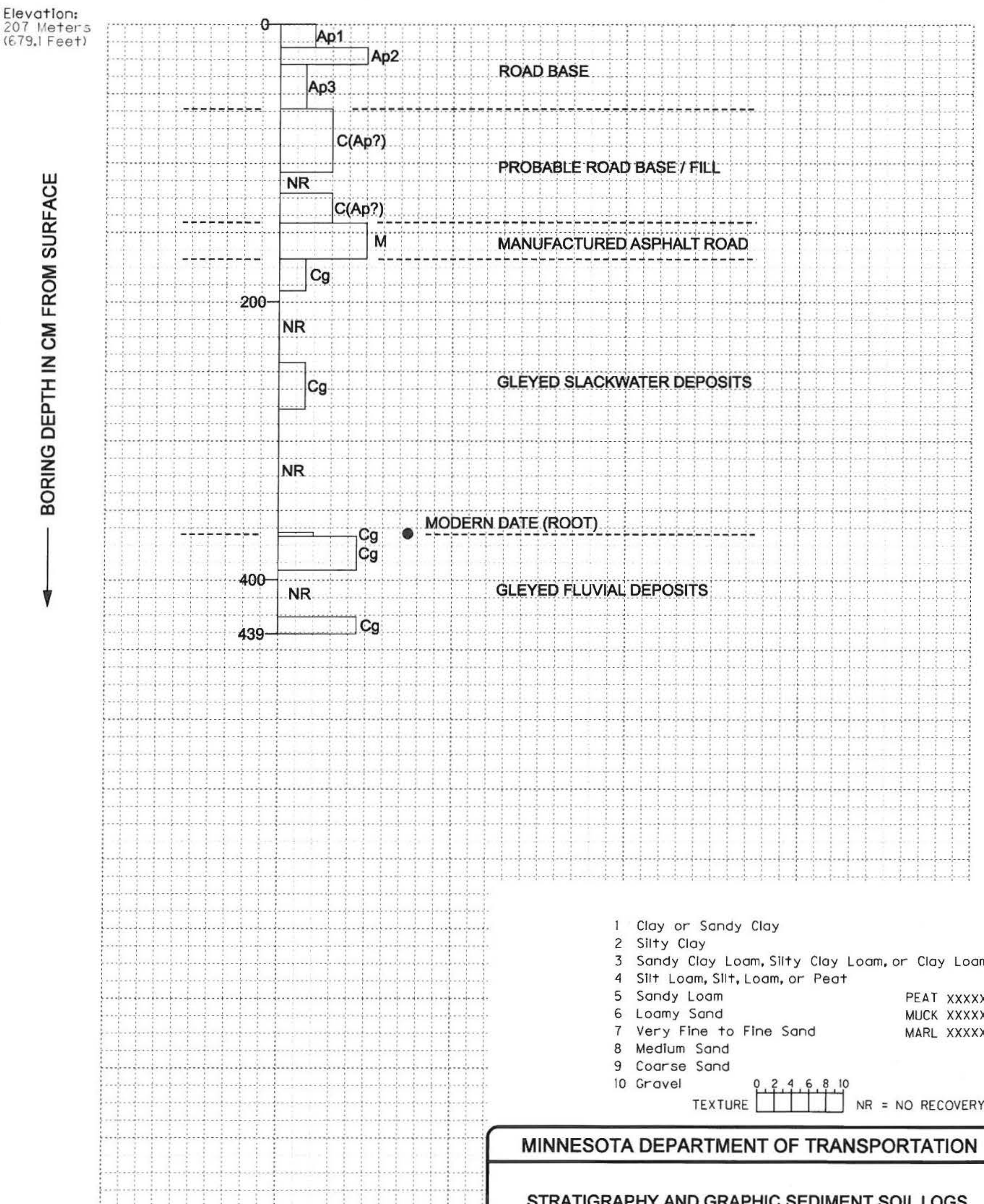
10GD-03



MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY AND GRAPHIC SEDIMENT SOIL LOGS OF FILL IN A BEDROCK CHANNEL IN AREA 4

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO.
12C

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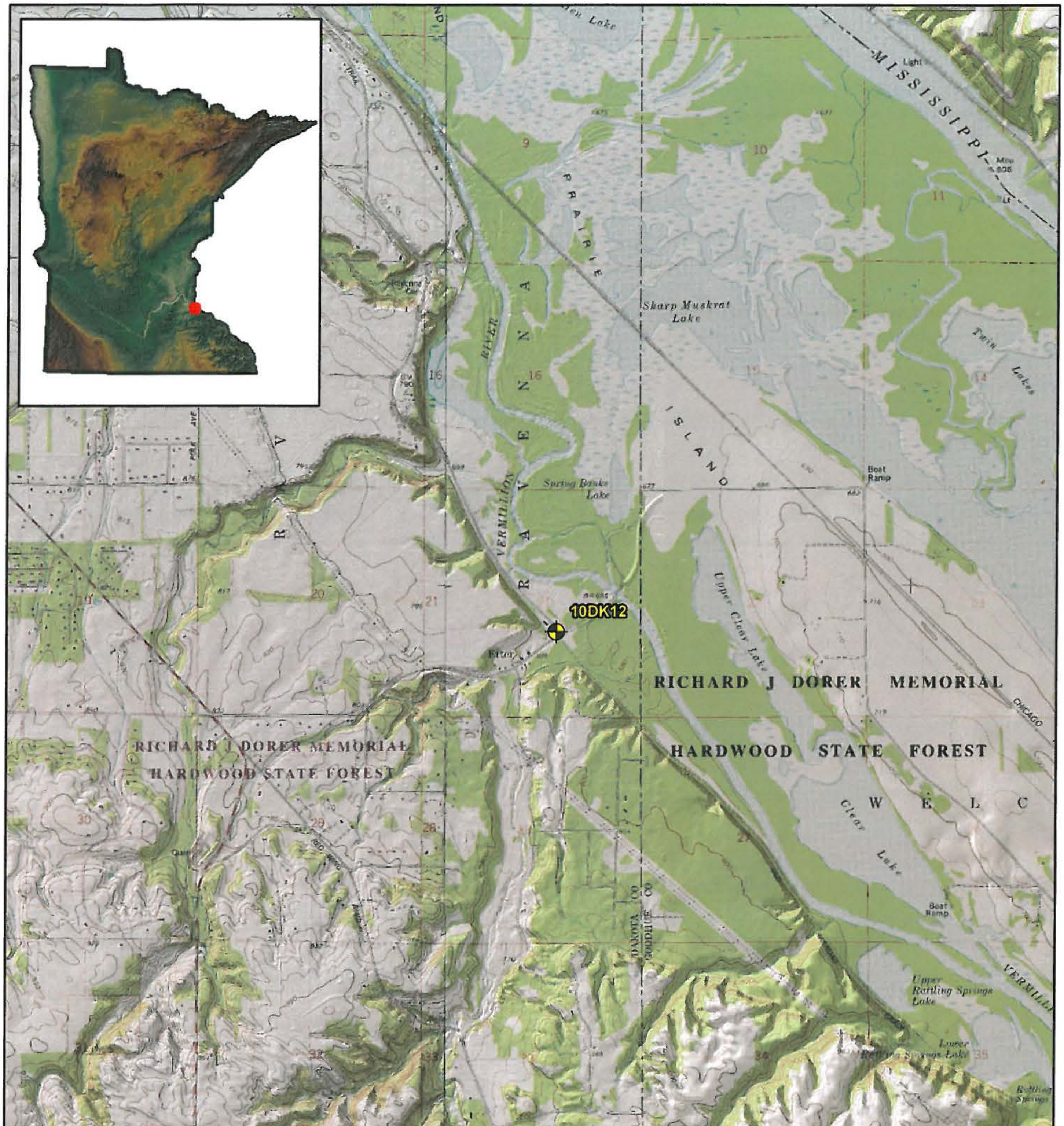

NOTES

Basemap Source: USGS 7.5' Minute Series Topographic Quadrangles
Projection: UTM Zone 15 North
Horzontal Datum: NAD83
Units: Meters

LEGEND

Sediment / Soil Cores

N

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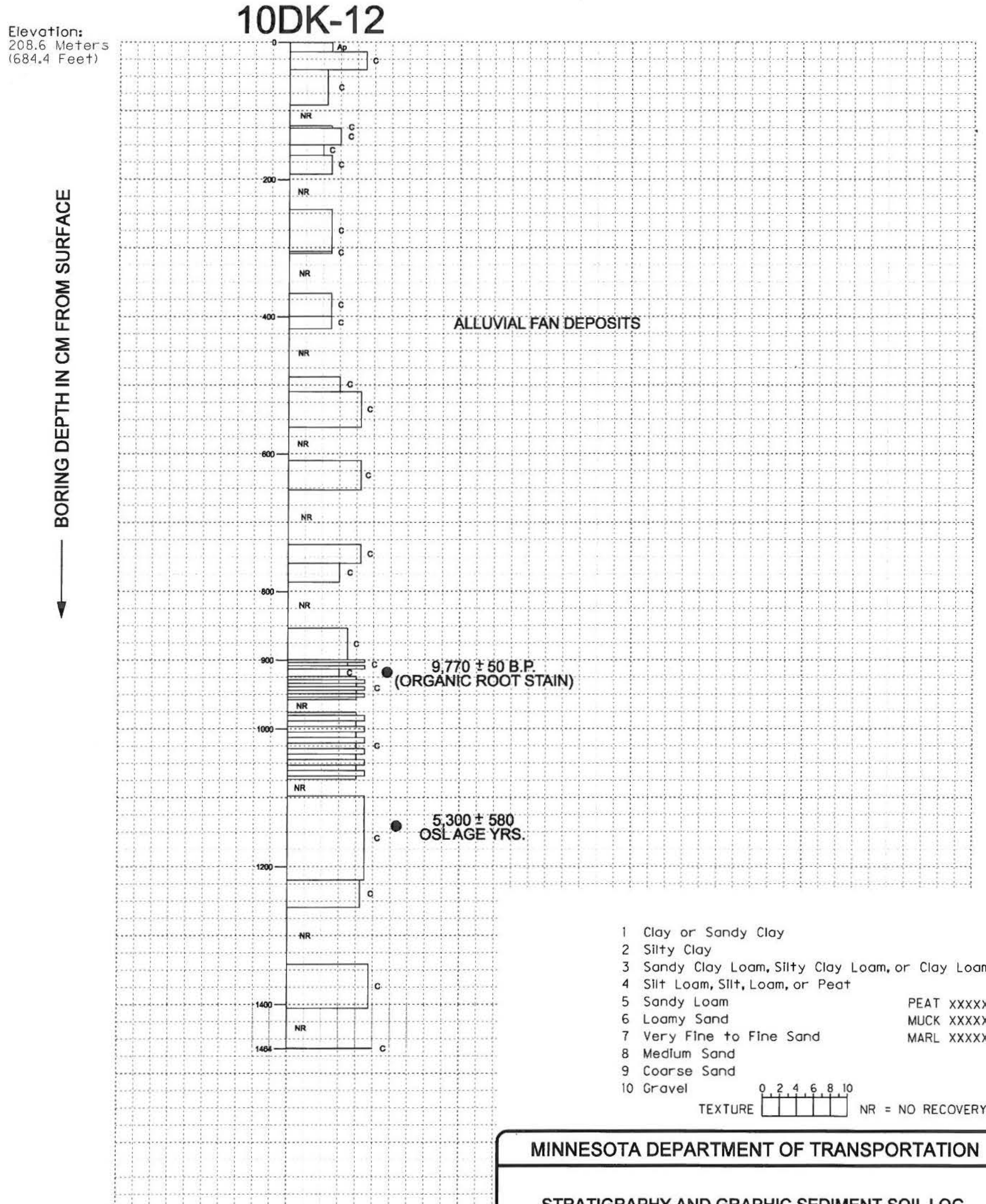
MINNESOTA DEPARTMENT OF TRANSPORTATION

FIGURE 13
Area 5 Core Location

Scale: 0 0.25 0.5 Kilometers	Date: SEPTEMBER, 2011
Prepared by: JJW1	Project No: 07M095

Path: X:\MS\IE\2007\07m095\GIS\mxd\mz_report_figure13.mxd



MINNESOTA DEPARTMENT OF TRANSPORTATION

STRATIGRAPHY AND GRAPHIC SEDIMENT SOIL LOG AT THE MARGIN OF THE HOLOCENE MISSISSIPPI VALLEY

SCALE AS SHOWN	PROJECT ID 07M095

DATE: 9/8/11
PREPARED BY: CKV
CHECKED BY: CMH1

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FIGURE NO.
14

09/08/2011 11:56:51 AM ckv x:\ms\ie\2011\11M018\cad\exhibits and figures\11M018_cores.dgn

Appendix A
List of Abbreviations, Acronyms, and Symbols

List of Abbreviations, Acronyms, and Symbols

AMS	Accelerator Mass Spectrometer
B.P.	Before Present (1950 A.D. base datum is used in radiocarbon chronology)
^{14}C	Carbon-14 (radiocarbon)
CAD	Computer aided drafting
cal. yrs. B.P.	Calendar years Before Present where "present" equals 1950 A.D.
drg	Digital Raster Graphic
Foth	Foth Infrastructure & Environment, LLC
GIS	Geographic Information System
GPS	Geographic Positioning System
LfSA	Landform Sediment Assemblages
Mn/DOT	Minnesota Department of Transportation
NRCS	Natural Resource Conservation Service
OSL age yrs.	Optically Stimulated Luminescence age in calendar years
QC	Quality Control
T.H.	Trunk Highway
U.S.	United States
USDA	United States Department of Agriculture
UTM	Universal Transverse Mercator – Coordinate System
WGS84	World Geodetic System 1984

Appendix B

Glossary of Terms

Glossary of Terms

alluvial fan. A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a valley upon a plain or broad valley, or where a tributary stream is near or at its junction with the main stream, or wherever a constriction in a valley abruptly ceases or the gradient of the stream suddenly decreases; it is steepest near the mouth of the valley where its apex points upstream, and it slopes gently and convexly outward with gradually decreasing gradient.

alluvium. A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semisorted sediment in the bed of the stream or on its floodplain or delta, as a cone or fan at the base of a mountain slope; esp. such a deposit of fine-grained texture (silt or silty clay) deposited during time of flood.

bar [streams]. A ridgelike accumulation of sand, gravel, or other alluvial material formed in the channel, along the banks, or at the mouth, of a stream where a decrease in velocity induces deposition; e.g., a *channel bar* or a *meander bar.*

basement material. The undifferentiated complex of rocks that underlines the rocks of interest in an area.

bluff. A high bank with a broad precipitous, sometimes rounded cliff face overlooking a plain or a body of water.

catastrophic flood. A sudden, violent, short-lived, flood usually eroding a region or subregion.

chute. A narrow stream or river channel through which water flows rapidly; usually during overflow stages.

colluvium. A general term applied to any unconsolidated sediment deposited by rainwash, sheetwash, slope failure, or slow continuous downslope creep, usually collecting at the base of slopes or hillsides.

core [drill]. A cylindrical section of sediment or rock, usually 5-10 cm in diameter and up to several meters in length, taken as a sample of the interval penetrated by a core bit, and brought to the surface for geologic examination and/or laboratory analysis.

cross-section. (a) A diagram or drawing that shows features transected by a given plane; specifically a vertical section drawn at right angles to the longer axis of a geologic or geomorphic feature, such as the mean direction of flow of a stream. (b) An actual exposure or cut that shows transected geologic features.

delta. The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area, crossed by many distributaries of the main river, perhaps extending beyond the general trend of the coast, and resulting from the accumulation of sediment supplied by the river in such quantities that it is not removed by tides, waves, and currents. Most deltas are partly subaerial and partly below the water. The term was introduced by Herodotus in the 5th Century B.C. for the tract of land, at the mouth of the Nile River, whose outline broadly resembled the Greek capital letter "delta", Δ, with the apex pointing upstream.

depositional environment. The type of environment under which sediments are deposited (e.g., fluvial, eolian, glacial, high energy, low energy). The location of a cultural site in reference to the surrounding landscape plays an important factor in the changes that occur to it over time. Common natural processes that alter the site once it is abandoned include erosion and sedimentation. Lack of deposition may allow many cultures to exist on the same land surface over a great time span. Rapid deposition may diffuse those same cultures over a thick sedimentary sequence.

disturbed area. Any land surface having been disturbed, changed, or modified from its natural condition by, or due to activities related to, recent human actions (e.g., quarries, mines).

exotic. Describes a rock or mineral that is derived from another geographic region and is not derived from the local underlying or adjacent bedrock.

floodplain. (a) The surface or strip of relatively smooth land adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks. It is built of alluvium carried by the river during floods and deposited in the sluggish water beyond the influence of the swiftest current. A river has one floodplain and may have one or more terraces representing abandoned floodplains. (b) Any flat or nearly flat lowland that borders a stream and that may be covered by its waters at flood stages; the land described by the perimeter of the maximum probable flood.

geomorphologist. A scientist that studies geomorphology.

geomorphology. (a) The science that treats the general configuration of the Earth's surface; specifically the study of the classification, description, nature, origin, and development of present landforms and their relationships to underlying structures, and of the history of geologic changes as recorded by these surface features. The term is esp. applied to the genetic interpretation of landforms, but has also been restricted to features produced only by erosion or deposition. The term was applied widely in Europe before it was used in the U.S., where it has come to replace the term *physiography* and is usually considered a branch of geology; in Great Britain, it is usually regarded as a branch of geography. (b) The science of both ancient and present day landscapes and how they evolved through time.

glaciofluvial. Pertaining to the meltwater streams flowing from wasting glacier ice and esp. to the deposits and landforms produced by such streams, as kame terraces and outwash plains; relating to the combined action of glaciers and streams.

gleyed sediment. Sediment developed under low oxygen conditions, typically under poor drainage or subaquatic environments resulting in reduction of iron and other elements. Gleyed sediments may be gray, blue, green, or olive in color. Abbreviated as a lower case "g" behind a master soil horizon designation in geologic core logs (e.g., Bg or Cg-horizon).

gorge. A narrow and deep valley with very steep to vertical banks and that may have running water at the bottom.

Holocene. An epoch of the Quaternary period, from the end of the Pleistocene, approximately 10,000 years ago, to the present time; also, the corresponding series of rocks and deposits. When the Quaternary is designated as an era, the Holocene is considered to be a period.

Holocene, radiocarbon age. The Holocene radiocarbon age is defined as 10,000 ^{14}C years B.P. to present.

horizons [soil]. A layer of soil that is distinguishable from adjacent layers by characteristic physical properties such as structure, color, or texture, or by chemical composition, including content of organic matter or degree of acidity or alkalinity. Soil horizons are generally designated by a capital letter, with or without a numerical annotation (e.g., A-horizon, C1-horizon).

hydrology. The science that deals with global water (both liquid and solid), its properties, circulation, and distribution, on and under the Earth's surface and in the atmosphere, from the moment of its precipitation until it is returned to the atmosphere through evapotranspiration or is discharged into the ocean. In recent years the scope of hydrology has been expanded to include environmental and economic aspects.

infinite date. An age exceeding the maximum detection limits of radiocarbon or other radiometric dating isotopes. The name implies that the age of the sample could go back to a time approaching infinity.

lacustrine. (a) Pertaining to, produced by, or formed in a lake or lakes; e.g., "lacustrine sands" deposited on the bottom of a lake, or a "lacustrine terrace" formed along its margin. (b) Growing in or inhabiting lakes; e.g., a "lacustrine fauna." (c) Said of a region characterized by lakes; e.g., a "lacustrine desert" containing the remnants of numerous lakes that are now dry.

landform. Any physical, recognizable form or feature of the Earth's surface, having a characteristic shape, and produced by natural causes; it includes forms such as plain, hill, terrace, slope, esker, and dune. Taken together, the landforms make up the surface configuration of the Earth.

landform sediment assemblage (LfSA). A landform or set of similar landforms that are linked with the same or similar underlying lithostratigraphic units.

landscape. (a) The distinct set of *landforms*, esp. as modified by geologic forces that can be seen in a single view, e.g., glacial landscape. (b) [Mn/Model] A "major" *landform* or set of *landforms* generated by a particular geologic process; the term "major" refers to the relative size of *landforms,* which is on a sliding scale.

landscape suitability ranking. (a) A ranking used to evaluate the potentials for the land surface and subsurface intervals to have and preserve in situ cultural deposits based upon stratigraphic ages and either post-depositional or depositional environments. This ranking does not predict archaeological site locations, it predicts landscapes and paleolandscapes that could contain or not contain in situ sites. (b) The numerical product of the *age ranking* and *depositional environment ranking*.

levee [streams]. (a) see *natural levee.* (b) An artificial embankment built along the bank of a watercourse or an arm of the sea, to protect land from inundation or to confine streamflow to its channel.

lithofacies. A lateral, mappable subdivision of a designated stratigraphic unit, distinguished from adjacent sub-divisions on the basis of lithology, including all mineralogic and petrographic characters and those paleontologic characters that influence the appearance, composition, or texture of the rock; a *facies* characterized by particular lithologic features. Laterally equivalent lithofacies may be separated by vertical arbitrary-cut-off planes, by intertonguing surfaces, or by gradational changes.

made land [soil]. Spatial areas filled with earth, earth and refuse, or refuse and is typically created under the control of man.

mantle [geol]. A general term for an outer or overlying covering material of one kind or another.

marginal channel. A channel formed by a stream flowing along the outer margin or paleo-margin of a catastrophic flood landscape.

meander [streams]. n. (a) One of a series of regular freely developing sinuous curves, bends, loops, turns, or windings in the course of a stream. It is produced by a mature stream swinging from side to side as it flows across its *floodplain* or shifts its course laterally toward the convex side of an original curve. (b) valley meander.--v. To wind or turn in a sinuous or intricate course; to form a meander.

model. A working hypothesis or precise simulation, by means of description, statistical data, or analogy, of a phenomenon or process that cannot be observed directly or that is difficult to observe directly. Models may be derived by various methods (e.g., by computer, from stereoscopic photographs, or by scaled experiments).

natural levee. A long broad low ridge or embankment of sand, silt, or other material, built by a stream on its floodplain and along both banks of its channel during flood stage when the coarser sediment is deposited as a result of suddenly decreased velocity once spilling over to the floodplain.

nivation hollow. A shallow depression or hollow in a mountainside or hillside that is or was either permanently or intermittently occupied by a snow patch, and that is subjected to the process of nivation. Nivation is the process of the hollowing out of fine grained sediment from the edges of a shrinking snow patch via meltwaters entraining this sediment in sheetwash or rivulets.

nivation ridge. A low convex embankment of fine-grained sediment deposited downslope from a nivation hollow via snow patch meltwaters. The fine material is carried by either sheetwash or rivulets.

optically stimulated luminescence (OSL). A method used to determine the absolute age of an aliquot of minerals. Electrons get trapped in the crystal lattices of minerals after being shielded from the sunlight by overlying sediments. While buried in the dark, a certain amount of electrons continue to slowly and relatively uniformly escape through time. More escape with more time passed. Once a mineral sample is collected in the dark, it may be stimulated in the laboratory again to release the remaining electrons, which are then measured and calculated as a ratio against the expected full capacity of electrons had none ever escaped. This ratio then determines the age of the sample.

overbank deposits. Fine-grained sediment (silt and clay) deposited from suspension on a floodplain by floodwaters that cannot be contained within the stream channel.

oxide. A mineral compound where oxygen is linked with one or more metallic elements like iron or manganese. Iron oxides may give the appearance of "rust" or colors associated with, for example, the Munsell 10 year hue and both higher chromas and values.

paleo-valley. A catch-all term used for ancient valleys that are now occupied by wetlands or underfit streams. Paleo-Valley landscapes could also be included in the Glaciofluvial landscape.

paleochannel. A remnant of a stream channel cut in older sediment or rock and filled by the sediments of younger overlying rock.

peat. An unconsolidated deposit of semicarbonized plant remains in a water saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75 percent).

ped. A naturally formed unit of soil structure, such as granule, block, subangular block, plates, etc.

ped coating. A naturally formed sedimentary layer that partially or wholly envelopes a unit of soil structure. Typically the coat consists of clay particles and is smooth and shiny in appearance to the unaided eye.

pediment. A term used in geomorphology to describe a gently sloping bedrock erosional surface formed by either alluvial or colluvial (e.g., sheetwash) waters under arid or semiarid conditions and at or near the base of a mountain, bluff, or escarpment. The bedrock surface slope may be mantled by a thin veneer of younger alluvium or colluvium derived from the receding mountain or escarpment, and in transit across the surface.

pedologic. A term used in soil classification for the collection of natural earthy materials on the Earth's surface, in places modified or even made by man, containing living matter, and supporting or capable of supporting plants out-of-doors. The lower limit is normally the lower limit of biologic activity, which generally coincides with the common rooting of native perennial plants.

pedology. One of the disciplines of soil science. The study of soil morphology, genesis, and classification.

Pleistocene. An epoch of the Quaternary period, after the Pliocene of the Tertiary and before the Holocene; also, the corresponding worldwide series of rocks. It began two to three million years ago and lasted until the start of the Holocene some 10,000 years ago. When the Quaternary is designated as an era, the Pleistocene is considered to be a period.

Pleistocene, terminal, radiocarbon age. The end of the Pleistocene is defined as 10,000 years B.P.

radiocarbon. Radioactive carbon.

radiocarbon dating. A method of determining an age in years by measuring the concentration of carbon-14 remaining in an organic material, usually formerly living matter, but also water bicarbonate, etc. The method, worked out by Willard F. Libby, U.S. chemist, in 1946-1951, is based on the assumption that assimilation of carbon-14 ceased abruptly on removal of the material from the Earth's carbon cycle (i.e., on the death of an organism) and that it thereafter remained a closed system. Most carbon-14 ages are calculated using a half-life of 5730$\pm$40 years or 5568$\pm$30 years. Thus the method is useful in determining ages in the range of 500 to 30, 000 or 40,000 years, although it may be extended to 70,000 years by using special techniques involving controlled enrichment of the sample in carbon-14.

redox condition. (a) shorthand for reduction-oxidation. Oxidation is the loss of electrons or an increase in oxidation state by a molecule, atom or ion. Reduction is the gain of electrons or a decrease in oxidation state by a molecule, atom or ion. In sediments, oxidized colors are typically have 10YR and 7.5YR or redder Munsell hues (reds, browns and yellows), and reduced colors tend to come more from the 5Y, 5GY, 5G, 5BG, and 5B Munsell hues (grays, greens and blues).

sedimentary rock. (a) A rock resulting from the consolidation of loose sediment that has accumulated in layers; e.g., a clastic rock (such as conglomerate or tillite) consisting of mechanically formed fragments of older rock transported from its source and deposited in water or from air or ice; or a chemical rock (such as rock salt or gypsum) formed by precipitation from solution; or an organic rock (such as certain limestones) consisting of the remains or secretions of plants and animals.

slough [mining] pron. *sluff.* Fragmentary rock or aggregate material that has crumbled and fallen away from the sides of a borehole and is typically seen at the top of the core sample when the sampling tool is opened.

soil profile. A vertical section of a soil that displays all its horizons.

solum. The upper part of a soil profile, typically the A and B horizons.

stratigraphic unit. A stratum or body of adjacent strata recognized as a unit in the classification of a rock sequence with respect to any of the many characters, properties, or attributes that rocks may possess (ISG, 1976, p. 13), for any purpose such as description, mapping, and correlation. Rocks may be classified stratigraphically on the basis of lithology (lithostratigraphic units), or properties (such as mineral content, radioactivity, seismic velocity, electric-log character, chemical composition) in categories for which formal nomenclature is lacking.

stratigraphy. (a) The science of rock strata. It is concerned not only with the original succession and age relations of rock strata but also with their form, distribution, lithologic composition, fossil content, geophysical and geochemical properties -- indeed, with all characters and attributes of rocks as *strata;* and their interpretation in terms of environment or mode of origin, and geologic history. All classes of rocks, consolidated or unconsolidated, fall within the general scope of stratigraphy. (b) The arrangement of strata, esp. as to geographic position and chronologic order of sequence.

terrace [geomorph]. (a) Any long, narrow, relatively level or gently inclined surface, generally less broad than a plain, bounded along one edge by a steeper descending slope and along the other by a steeper ascending slope; a large bench or steplike ledge breaking the continuity of a slope. The term is usually applied to both the lower or front slope (the riser) and the flattish surface (the tread), and it commonly denotes a surface of a valley-contained, aggradational form composed of unconsolidated material as contrasted with a *bench* eroded in solid rock or till, for example. A terrace commonly occurs along the margin and above the level of a body of water, marking a former water level; e.g., a *stream terrace.* (b) A term commonly but incorrectly applied to the deposit underlying the trend and riser of a terrace, esp. the alluvium of a stream terrace; "this deposit ... should more properly be referred to as a fill, alluvial fill, or alluvial deposit, in order to differentiate it from the topographic form" (Leopold et al. 1964, p. 460).

thalweg. The line of deepest points along a streambed. Typically a smaller deeper channel within the overall streambed channel.

trench [geomorph]. A steep-sided valley, canyon, gorge or other depression eroded by running water such as a river.

topography. (a) The general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and man-made features. (b) The natural or physical surface features of a region, considered collectively as to form; the features revealed by the contour lines of a map.

UTM. Universal Transverse Mercator Coordinate System.

Appendix C
Map Unit Field Code Key Table For Mn/Model v. 6.0

MAP UNIT FIELD CODE KEY TABLE FOR Mn/MODEL v. 6.0
(last modified December 16, 2011)

GEOMORPHIC FIELD CODES

Can be supplemented with USGS Digital Elevation Data layer and its derivative layers (Slope; Relative Elevation; Surface Roughness). Also can be supplemented with MPCA Stream Order layer, although this is a coarser scale than Code No. 10.

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 1 GEOMORPHIC REGION (GEOM_REG1)				Polygons can be adapted from editing the DNR GIS Minnesota Geomorphology coverage or created by new landform-sediment assemblage mapping for Mn/Model.
	No Distinction Made	NO_DIST	*	
	Glacial Lobe	GLA_LOB	L	
	Glacial Lake Plain	GLA_LAK	P	
	Glaciofluvial Valley	GLF_VAL	V	
	Glacial-Scoured Bedrock Terrain	GLA_SBRT	B	
	Bedrock Terrain	BRT	T	
CODE NO. 2 GEOMORPHIC REGION IDENTIFIER (REGION_ID2)				This code consists of the geographic or commonly used name for a **Geomorphic Region**.
	No Distinction Made	NO_DIST	*	
Glacial Lobe				
	Des Moines	DES	D	
	Grantsburg	GRANT	G	
	Koochiching	KOOCH	K	
	Pre-Wisconsinan	PRE_WI	P	
	Rainy	RAINY	Y	
	Red River	RED	R	
	St. Louis	STL	S	
	Superior	SUPER	X	
	Wadena	WADEN	W	
Glacial Lake Plain				
	Lake Agassiz	LAK_AGA	LA	This value excludes the Beltrami Arm of Lake Agassiz.
	Lake Agassiz, Beltrami Arm	LAK_AGAB	LB	
	Lake Aitkin	LAK_AIT	LI	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Lake Duluth	LAK_DUL	LD	
	Lake Upham	LAK_UPH	LU	
	Lake Minnesota	LAK_MIN	LM	
	Lake Benson	LAK_BEN	LE	
Glaciofluvial Valley				
	Glacial River Warren	RIV_WAR	VW	
	St. Croix River Valley	STC_VAL	VS	
	Mississippi River Valley	MIS_VAL	VM	
	Rum River Valley	RUM_VAL	VU	
	St. Louis River Valley	STL_VAL	VT	
	Sauk River Valley	SAK_VAL	VK	
Bedrock Terrain				
	Border Lakes Area	BORDER	BO	
	Giants Range	GIANT	GI	
	Mesabi Range	MESAB	ME	
CODE NO. 3 GEOMORPHIC SUB-REGION (GEOM_SUBR3)				Polygons can be adapted from editing the DNR GIS Minnesota Geomorphology coverage or created by new landform-sediment assemblage mapping for Mn/Model.
	No Distinction Made	NO_DIST	*	
	Ground Moraine	GRO_MOR	G	
	End Moraine	END_MOR	E	
	Beach (Level)	BEA_LEV	B	
	Eolian Dune Field	EOL_FLD	D	
	Drumlin Field	DRU_FLD	U	
	Outwash Plain	OUT_PLA	O	
	Paleo-Valley	PAL_VAL	Y	This value can include outwash, collapsed outwash, tunnel valley, glacial lake outlet, etc. cut during glacial activity.
	River Valley	RIV_VAL	R	
	Sand Plain	SAND_PLA	S	This value is descriptive (i.e., not genetic) for a sand plain of unknown or complex origin(s).

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 4 GEOMORPHIC SUB-REGION IDENTIFIER (SUBREG_ID4)				This code consists of the geographic or commonly used name for a **Geomorphic Sub-Region**.
	No Distinction Made	NO_DIST	*	
Moraine				
	Alexandria	ALEX	AX	
	Algona	ALGO	AG	
	Altamont	ALTA	AL	
	Ann	ANN	AN	
	Bemis	BEMI	BE	
	Big Stone	BIGS	BS	
	Cloquet	CLOQ	CL	
	Culver	CULV	CU	
	Dent	DENT	DE	
	Erskine	ERSK	ER	
	Frazee	FRAZ	FR	
	Guthrie	GUTH	GU	
	Highland	HIGH	HI	
	Itasca	ITAS	IT	
	Knife	KNIF	KI	
	Mille Lacs	MILL	MI	
	Nashwauk	NASH	NA	
	Nemadji	NEMA	NE	
	Nickerson	NICK	NI	
	Outing	OUTI	OU	
	Pine City	PINE	PI	
	St. Croix	STCR	ST	
	Sugar Hills	SUGA	SU	
	Vermillion	VERM	VE	
Beach (Level)				
	Blanchard	BLAN	BL	
	Campbell	CAMP	CA	
	Emerado	EMER	EM	
	Herman	HERM	HE	
	Hillsboro	HILL	HI	
	Lower Campbell	LOCA	LO	
	McCauleyville	MCCA	MC	
	Norcross	NORC	NO	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Ojata	OJAT	OJ	
	Tintah	TINT	TI	
Eolian Dune Field				
Drumlin Field				
	Wadena	WAD_DRU	WD	
	Toimi	TOI_DRU	TD	
	Pierz	PIE_DRU	PD	
	Brainerd	BRA_DRU	BD	
	Automba	AUT_DRU	AD	
Outwash Plain				
	Anoka Sand Plain	ANOKA	AK	The Anoka Sand Plain is generally considered an outwash or lake plain (Wright, 1972; Patterson, 1992; Meyer and Patterson, 1997). However, much of the area was subsequently modified by eolian processes forming dunes and possibly sand sheets.
	Park Rapids	PARK_OP	PR	
River Valley				
	Blue Earth Valley	BLU_VAL	BLU	
	Rainy River Valley	RAINY_VAL	RA	
	Red River Valley	RED_VAL	RE	
	Root River Valley	ROOT_VAL	RO	
	Rock River Valley	ROCK_VAL	RK	
	Rum River Valley	RUM_VAL	RU	
	Minnesota Valley	MINN_VAL	MN	The Minnesota Valley is separated from the geomorphically broader Glacial River Warren valley because it contains the bulk of the Holocene-aged sediments
	St. Croix Valley	STC_VAL	CRX	
	Sauk Valley	SAUK_VAL	SK	
	Upper Mississippi Valley - Headwaters Reach	MISS_HEAD	UMH	The headwaters region is typified by a series of lake basins interconnected by ancient outwash channels.
	Upper Mississippi Valley - Glacial Lake Aitkin Reach	MISS_AITKIN	UMA	The Mississippi River Valley cross-cuts the relatively flat Glacial Lake Aitkin basin.

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Upper Mississippi Valley - Brainerd to St. Cloud Reach	MISS_BRAIN	UMB	The Mississippi River Valley cross-cuts a broad outwash valley train.
	Upper Mississippi Valley - St. Cloud to Minnesota Valley Confluence	MISS_STCLD	UMS	
	Upper Mississippi Valley - Glacial River Warren Reach	MISS_WARREN	UMW	
	Upper Mississippi Valley - St. Croix Valley Confluence to Iowa Border	MISS_STCROIX	UMC	
CODE NO. 5 LANDSCAPE (LANDSCAPE5)				Landscapes that are composed of one or more related **Landforms**.
	No Distinction Made	NO_DIST	*	
	Upland, Undifferentiated	UPL_UNDIFF	U	
	Active Ice	ACT_ICE	I	
	Stagnant Ice	STAG_ICE	S	
	Ice Contact	ICE_CONT	N	
	Pediment	PEDIMENT	P	
	Glaciofluvial	OUTWASH	O	
	Catastrophic Flood	CAT_FLOOD	C	Kehew (1982)
	Glaciolacustrine	GLAC_LAC	A	
	Collapsed Sand Plain	C_SAND_PLA	D	This value is used for a sand plain of unknown or polygenetic origin that for the most part exhibits the muted morphology of a buried, collapsed stagnant ice landscape. The depositional environment (glaciofluvial, glaciolacustrine, eolian, or in combination) of the covering sand may or may not be related in part or in whole to the buried ice and its stagnation. Such a sand plain is distinguished from a strictly Stagnant Ice Landscape due to its unknown, and likely polygenetic origin, and the apparent discordance between the origin of the sand body and its existing morphology.
	Collapsed Meltwater Trough	MELT_T	T	This value is applied to generally linear troughs and associated landforms that originally developed as tunnel valleys under active ice conditions (Wright, 1973). However, in some locations, following retreat of the formative glacial ice, they have a longer, more complex polygenetic origin that includes subsequent glaciofluvial, stagnant ice, glaciolacustrine and lacustrine processes. Collapsed Meltwater Troughs are distinguished here at

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
				the landscape level because of their clear definition by sharp relief, scale, and polygenetic origin considerably removed from a strictly Glacialfluvial Landscape.
	Meltwater Trough Fan	MELT_F	MF	This value is used for large positive features that are interpreted as fans at the mouths of Collapsed Meltwater Troughs, or tunnel valleys (Patterson, 1994). The associated sediment assemblage consists of interstratified sand, gravel and diamicton. This value is discontinuous, unlike other modes of glacial fluvial landscape that tend to exhibit a strong linearity. Nevertheless, they are widespread, and cumulatively exist at the landscape scale.
	Paleo-Valley	PALEO_VAL	Y	
	Peatland	PEAT	B	
	Valley Terrace	VAL_TERR	V	
	Floodplain	FLOOD	F	
	Valley Margin	VAL_MARG	M	This value includes depositional forms at the foot of valley margin slopes and relatively steep sideslopes with sharply defined shoulder and footslope.
	Eolian	EOLIAN	E	
	Lacustrine	LAKE	L	*This value may include **River Lake** and river **Delta** landforms.*
CODE NO. 6 LANDSCAPE GEOGRAPHIC OR INFORMAL IDENTIFIER (LNDSCP_ID6)				This code consists of the geographic or commonly used name for a **Landscape** in a particular **Geomorphic Region** or **Geomorphic Sub-Region**.
	No Distinction Made	NO_DIST	*	
CODE NO. 7 LANDFORM (LANDFORM7)				This code consists of individual values of **Landscape** at a landform scale.
	No Distinction Made	NO_DIST	*	
	Alluvial Fan	FAN	AF	The morphologic transition between **Alluvial Fan** and **Colluvial Slope** can be gradational. In general, **Alluvial Fan** includes fan-shaped forms of mappable size. Smaller fans not practical to differentiate at the 1:24,000 scale of mapping, whether alluvial or colluvial, are included in the **Colluvial Slope** value. Where multiple **Alluvial Fans** have coalesced, no attempt is made to differentiated individual fans. This code refers to alluvial fan-deltas, which are usually at or near the floodplain along major rivers such as in the Mississippi Valley.
	Alluvial Fan-Delta	F_DELTA	FD	This code distinguishes the distal position of a fan-delta from the proximal position. The distal fan-delta position is typically characterized by a lower landscape position, more poorly drained soils, and in some locations a
	Alluvial Fan-Delta,	FD_DISTAL	FD(D)	thinner and / or finer sediment assemblage and to some degree, different

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Distal			sediment processes, compared to the proximal fan-delta position.
	Alluvial Fan, Distal	FAN_DISTAL	AF(D)	This code distinguishes the distal position of an alluvial fan from the proximal and medial positions. The distal fan is dominated by processes (distributaries and wash) that differ from the proximal fan environment. Also, the distal fan is thinner than the proximal fan, and can be underlain by shallower and younger geomorphic surfaces. This code is used within large fans typically developed in the Mississippi River valley.
	Arterial Drain Patterned Bog (Water Track)	ART_BOG	AB	See Glaser et al. (1981), Wright and Glaser (1983), and Eng (1980).
	Bar	BAR	B	This value is usually, but not exclusively, used in conjunction with the **Catastrophic Flood Landform**.
	Bar, Distal	BAR_DISTAL	B(D)	This code distinguishes the distal position of a fluvial bar from the proximal position. The distal bar position is typically characterized by a lower landscape position, more poorly drained soils, and in some locations a thinner and / or finer sediment assemblage and to some degree, different sediment processes, compared to the proximal bar position.
	Beach Ridge, Spit, Cusp, or Shore	SHORE	SH	Geomorphological beach line.
	Colluvial Slope	COLLUV	C	The morphologic transition between **Alluvial Fan** and **Colluvial Slope** can be gradational. In general, **Colluvial Slope** includes various forms of slopes dominated by sheetflood depositional processes as well as those dominated by slumps and other slope failures. Smaller fans not practical to differentiate at the 1:24,000 scale of mapping, whether alluvial or colluvial, are included in the **Colluvial Slope** value. Areas of **Colluvial Slope** often are present but are too narrow to be reasonably mapped at a scale of 1:24,000.

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Compaction Ridge	COMP_RIDG	CR	Ridges of coarser grained sand and gravel deposited by streams that flowed on a lake plain between glacial lake stages, therefore covered by a layer of lake clays. Defined in the Glacial Lake Agassiz **Geomorphic Region** by Bluemle (1967).
	Crevasse Splay	SPLAY	CS	This value includes crevasse channels, splay channels, and splay overbank belts.
	Crevasse Splay Channel	CS_CHANNEL	CH	This code is used for significantly sized crevasse splay channels.
	Crevasse Splay Distributary Mouth Bar	CS_DIST_BAR	SD	This code is used for distributary mouth bars of substantial crevasse splays.
	Crevasse Splay Distributary Mouth Bar, Distal	CS_D_B_DISTA L	SD(D)	This code distinguishes the distal position of a crevasse splay distributary mouth bar from the proximal position. The distal distributary bar position is typically characterized by a lower landscape position, more poorly drained soils, and in some locations a thinner and / or finer sediment assemblage and to some degree, different sediment processes, compared to the proximal distributary bar position.
	Crevasse Splay Meander Belt	CS_MEANDER	CM	This code is used for meander belts of substantial crevasse splays.
	Crevasse Splay, Distal	CS_DISTAL	CS(D)	This code distinguishes the distal position of a crevasse splay from the proximal position. The distal crevasse splay position is typically characterized by a lower landscape position, more poorly drained soils, and in some locations a thinner and / or finer sediment assemblage and to some degree, different sediment processes, compared to the proximal crevasse splay position.
	Delta	DELTA	DE	This value does not differentiate between different types of deltas. It includes deltas formed in lakes; fan deltas, where a river enters a riverine lake; and, deltas deposited where a river enters a larger river valley.
	Depression	DEPR	D	As used in the code, **Depression** is a general descriptive term for a relatively small topographic basin. It usually is used in conjunction with glacial **Landscape**s. The value may include **Linked Depression**s or **Interdunal Depression**s where they are not differentiated. Some **Depression**s may be old abandoned quarries which are indistinguishable as to their origin without a historic landuse record search.
	Depression, Kettle	DEPR_KETTLE	DK	Ice-block meltout depressions or parts parts of depressions not typically occupied by standing water.
	Depression, Rectangular	DEPR_RECT	DB	This code is used for rectangular ice block depressions reflecting surface ice with little to moderate subsequent modifications.
	Disintegration Ridge	DIS_RIDGE	DS	Defined by the DNR for their (1:100k) geomorphology maps.
	Disturbed Areas	DISTURB	DI	This value primarily consists of quarries and pits, but can include vast construction sites and sewage treatment reservoirs. Excludes plowed fields.

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Doughnut	DOUGH	DO	
	Drainageway	DRAIN	DA	This value consists of low-order valleys that have a shallow "u" shape and ill-defined floodplain. They are typical of low-order upland valleys.
	Drumlin	DRUMLIN	DR	
	Dune	DUNE	ED	
	Erosional Residual	RESIDUAL	ER	A remnant of a once larger stratigraphic unit or body of rock that has been mostly eroded. This value is used in conjunction with **Catastrophic Flood** or, less frequently, **Outwash Landscapes**.
	Erosional Strath	STRATH	ST	A bench cut in bedrock or till by fluvial or glaciofluvial processes. It may or may not have a continuous or discontinuous veneer of younger fluvial deposits on it. This value is usually used in conjunction with **Catastrophic Flood** or **Outwash Landscapes**.
	Escarpment Complex	ESCARP_C	EC	This value is used in areas where the major landform is an escarpment with the **Glaciolacustrine** landscape and includes smaller **Terrace** and possibly **Beach Ridge** landforms which are not readily apparent at the 1:24,000 scale
	Esker	ESKER	EK	
	Floodplain, Undifferentiated	FLOOD	F	This value is mapped in lower order valleys where individual **Floodplain** types are not large enough, or distinct enough, to map at a scale of 1:24,000. Marshes and lakes on **Floodplain**s are considered subdivisions of **Floodplain**s and usually are not distinguished individually because many are seasonal and subject to large seasonal fluctuations in water depth and size. Individual sloughs on **Floodplain**s are not distinguished unless they are of considerable length and mapped as a **Paleochannel**. Otherwise, they are considered part of the lateral accretion **Floodplain** morphology.
	Floodplain, Type "w"	FL_W	FW	**Type "w" Floodplain**s have point bars or other channel migration features evident and recently active based on the lack, paucity, or type of vegetation. It often is associated with comparatively sparse or no vegetation; typically occurs between a marked discontinuity with other **Floodplain** types and the active river channel; and, lacking the aforementioned, may be an arbitrary distinction between **Type "w"** and **Type "x" Floodplain** types.
	Floodplain, Type "x"	FL_X	FX	**Type "x" Floodplain**s have point bars or other channel migration features evident, but they have not been recently active. They are usually vegetated.
	Floodplain, Type "y"	FL_Y	FY	Point bars or other channel migration features not evident on **Type "y" Floodplain**s, either due to burial by younger overbank deposits, or they were never present.
	Floodplain, Type "z"	FL_Z	FZ	**Type "z" Floodplain**s do not have evident point bars or other channel migration features; usually are surrounded or partially surrounded by **Valley Terrace** or **Catastrophic Flood Landscapes**; and/or are outside of, or otherwise isolated from, obvious former channel and/or overbank belts.
	Floodplain and Terraces, Undifferentiated	FLO&TERR	FN	This value is mapped in lower order valleys wide enough to have **Floodplain**s and **Terrace**s, but where individual **terrace** areas are not large

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
				enough, or distinct enough from **Floodplain** areas, to map at a scale of 1:24,000.
	Floodplain, Island Braided	FL_IB	FI	Floodplain with an island-braided pattern.
	Hillslope	HILL	H	This value refers only to relatively steep and high 1) valley walls along higher order valleys with floodplains; 2) ***upland*** hillslopes; and, 3) ***upland or valley*** slopes in bedrock terrains. It primarily consists of backslope hillslope components (*sensu* Ruhe, 1969). The upper limit usually is mapped where contour lines become more widely spaced, generally representing the position of the shoulder slope.
	Hummock	HUMMOCK	HU	As used in the code, **Hummock** is a general descriptive term for a relatively small topographic rise. It usually is used in conjunction with glacial **Landscapes**. The value may include Doughnuts and **Ice-Walled Lake Beds** where they are not differentiated.
	Ice-Block Kame Terrace	ICEBK_KAME	IK	An often ring-shaped kame terrace formed in a glaciolacustrine or glaciofluvial setting at the perimeter of a stagnating glacial ice block (Hudak and Hajic 1999; Hudak and Hajic in preparation)
	Ice-Walled Lake Bed	ICE_WALLED	IW	This value is mapped in conjunction with the **Stagnant Ice Landscape**. It is used for circular Hummocks where associated stratified fine-textured deposits >2m thick are interpreted as lake sediments.
	Ice-Walled Lake Beach Ridge	ICE_WAL_BR	IB	This value is mapped in conjunction with the **Stagnant Ice Landscape**. It consists of narrow, arcuate, ridges that rise above surrounding **Stagnant Ice** LsSA terrain. It often is associated with, but not necessarily adjacent to, **Hummocks** mapped as **Ice-Walled Lake Beds**
	Inter-Drumlin Trough	INTER_D	ID	This value is for troughs between drumlins.
	Interdunal Depression or Pond	POND	DP	This value refers to a **Depression** that is interpreted to have been formed wholly or in part by eolian processes. It typically, but not necessarily, is at least partially surrounded by **Eolian Dunes**. Such a depression may seasonally or perennially contain a relatively small water body.
	Island	ISLAND	I	If other **Landform** assignments are deemed more significant than the **Island**-lake or **Island**-river relationship, **Island** is not used. Islands may have complicated stratigraphy, but were not field tested during the Mn/Model project.
	Isthmus	ISTHMUS	IT	
	Kame	KAME	K	
	Kame Terrace	KAMET	KT	Stratified drift deposited in depressions and cavities in stagnant ice and left as irregular steep-sided hills when the ice melts.
	Lake	LAKE	LN	
	Lake, Kettle	LAKE_KETTLE	LK	Lakes occupying all or parts of kettle depressions.
	Lake Bed, Exposed	LAKEBED	LB	Exposure may be naturally or artificially caused. This value is generally used for lake basins of intermediate size, not relatively small **Depressions** or

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
				Linked Depressions that may have at one time supported small lakes or ponds, or relatively large lake **Plains**.
	Linked Depression(s)	DEPR_LINK	LD	See Kemmis (1991). This value is related to glacial karst development. Many areas mapped as **Depressions** may fall within this value genetically, but either the linkage between individual **Depressions** was unclear, or **Depressions** were too small to map at the scale of 1:24,000.
	Marginal Channel	MARG_CHAN	MC	This value is usually used in conjunction with **Catastrophic Flood** LsSA.
	Meander Belt	MEANDER	MB	This value is mapped in conjunction with lower or intermediate order streams in their valleys, and where they cross **Floodplains** or **Terraces** in valleys of higher order streams.
	Nivation Hollow	NIV_HOL	NH	This code is used for nivation hollows, basins that form under periglacial conditions.
	Nivation Hollow Ramp	NIV_HOL_RAMP	NR	This code is used for colluvial ramps that ascend to the openings of nivation hollows. They formed under periglacial conditions.
	Natural Levee	LEVEE	NL	**Natural Levees** form a continuum with lower, broader, more subtle rises of overbank deposits that are mapped as part of **Floodplain Types "y"** and **"z"** in some valleys.
	Natural Levee, Distal	LEVEE_DISTAL	NL(D)	This code distinguishes the distal position of a natural levee from the proximal position. The distal natural levee position is typically characterized by a lower landscape position, more poorly drained soils, a finer sediment assemblage, and in some locations a thinner sediment assemblage and to some degree, different sediment processes, compared to the proximal natural levee position.
	Outwash Fan, Apron	OUT_FAN	OF	
	Overbank Belt	OVERBANK	OB	**Overbank Belt** is used in conjunction with floodplains of relatively lower order streams where they cross **Floodplains** or **Terraces** in valleys of higher order streams.
	Ovoid-Shaped Bog (Ovoid Island)	OVOID_BOG	OV	See Heinselman (1963, 1970), Glaser et al. (1981), Wright and Glaser (1983), Minnesota Dept. of Natural Resources (1984), and Eng (1980).
	Paleochannel	PALEO_C	PC	This value includes distributary paleochannels on abandoned delta lobes.
	Pediment Slope	PEDIMENT	PD	This value may look similar to **Alluvial Fans** or **Colluvial Slopes** on topographic maps.
	Peninsula	PENIN	PE	
	Plain	PLAIN	P	This value usually is used in conjunction with, but is not limited to, **Outwash**, **Glaciolacustrine**, and glacial ice **Landscapes**. **Exposed Lake Bed** is used for exposed lake or glacial lake basins of intermediate or smaller size.
	Raised (Radial) Bog	RAD_BOG	RB	See Heinselman (1963; 1970), Glaser et al. (1981), Wright and Glaser (1983), Minnesota Dept. of Natural Resources (1984), and Eng (1980).
	Rapids, Nickpoint, Cascade, or Falls	RAPIDS	RP	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Ribbed Fen	RIB_FEN	RF	See Heinselman (1963, 1970), Glaser et al. (1981), Wright and Glaser (1983), and Eng (1980).
	River Channel, Active	RIVER	R	
	Riverine Lake	RIV_LAKE	RL	
	Rock Basin	ROCK_BAS	RS	This value is used in **Bedrock Terrains**.
	Rock Drumlins (Whale-backs)	ROCK_DRU	RD	This value is used in **Bedrock Terrains**.
	Rogen Moraine	ROG_MOR	RM	
	Roche Moutonnee	ROCHE	RH	This value is used in **Bedrock Terrains**.
	Sand Sheet	SHEET	ES	
	Spit	SP	SP	Spit
	Standing Water, Reservoir	RESERVOIR	LR	
	Summit	SUMMIT	S	See Ruhe (1969). In the code, this value is applied to **Bedrock Terrains** and erosional terrains only and primarily consists of summit slopes.
	Terrace	TERRACE	T	
	Terrace, High, Undifferentiated	H_TERRACE	HT	This value is mapped where multiple high terraces, or high and low terraces, are present, but reasonably can not be differentiated at the 1:24,000 scale of mapping.
	Tunnel Valley	TUN_VAL	TV	Valley carved by a stream flowing at the ice/land surface contact.
	"v"-Shaped Valley	V_VALLEY	V	This value consists of low-order valleys that have a "v" shape; little or no floodplain area; and, generally steep valley walls. Such valleys are often incised into the surrounding landscape, and may consist of the channel itself.
	Wave-Cut Platform	WAVE_CUT	WC	
CODE NO. 8 LANDFORM GEOGRAPHIC OR INFORMAL IDENTIFIER (LNDFRM_ID8)				This code consists of geographic or commonly used name for a **Landform**. It is to be added as needed.
	No Distinction made	NO_DIST	*	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 9 LANDFORM SUBDIVISION (LDFRM_SUB9)				
	No Distinction Made	NO_DIST	*	
	Depression, Ice-Block Ribs	DEP_RIBS	P	This code is used for slightly positive ribs, showing a rectangular pattern, within a rectangular ice block depression.
	Depression, Rectangular Ice-Block	DEP_RECT	R	This code is used for rectangular ice block depressions reflecting surface ice with little to moderate subsequent modifications.
	Floodplain, Island-Braided Channels	FL_IB_CHANNEL	B	This code is used to distinguish distinct braid channels within an Island-Braided Floodplain.
	Floodplain, Island-Braided Island	FL_IB_ISLAND	I	This code is used to distinguish distinct islands within an Island-Braided Floodplain.
	Pond	POND	PN	This code is used for a pond, or other small standing body of water. The code is generally used for smaller water bodies, often only partially filling a larger part of a landform basin.
CODE NO. 10 STREAM VALLEY ORDER (VLLY_ORD10)				Streams are ordered using the Strahler method (Strahler, 1964)
	Not Relevant or No Distinction Made	NO_DIST	*	
	1	1	1	
	2	2	2	
	3	3	3	
	Etc.	Etc.	Etc.	

Code Number and Title (GIS FIELD)	*Value*	*GIS Code Symbol*	*Map or Code-String Symbol*	*Comments*
CODE NO. 11 SURFACE CHARACTERISTICS AND MODIFICATIONS (SURFACE11)				*This code consists surface characteristics and modifications within a **Landform** or **Landscape** that are penecontemporaneous with, or post-date the development of the **Landform** or **Landscape**.*
	Not Present or No Distinction Made	NO_DIST	*	
	Boulder or Cobble Lag	BOULDER	R	
	Braided Channel Pattern	BRAID	B	
	Braided Channel Pattern with Shallow, Natural Standing Water	BRAID_MARSH	BM	
	Inundated Channel	INUNDATED	W	This code refers to recognizable channel landforms that are inundated with intermittently or permanently flowing water, such as a crevasse splay channel. It is used in the Upper Mississippi Valley where such landforms tend to be large.
	Island Braided Pattern	ISLAND_BR	IB	
	Dendritic Channel Pattern	DENDR	DD	
	Meandering Channel Pattern	MEANDER	S	
	Flood Scour Channel Pattern	FL_SCOUR	F	
	Distributary Pattern	DISTRIB	D	
	Pitted	PITTED	P	
	Wave or Current Modified, Subaerial	WAVE_AERIAL	WA	
	Wave or Current Modified, Submerged	WAVE_SUBMERGE	WS	This code usually refers to submerged **Islands**, **Wave-Cut Platforms,** and **Ice-Block Kame Terraces.**
	Water Modified	WATER_MOD	T	
	Water Modified, Marsh	WAT_MOD_MAR	TM	
	Wind Modified	WIND_MOD	N	
	Linear, Reticulated, or Orbicular Patterns	RIP_ICE	I	Pertains to patterns recognized on the Glacial Lake Agassiz plain. See Mollard (1983).
	Standing Water, Natural, Shallow	MARSH	MA	This value is used for areas with intermittent or permanent shallow water usually marked with a marsh symbol on USGS topographic maps. Larger areas are often mapped as **Peatlands**. This value is differentiated from **Standing Water, Natural** (lakes) by having relatively shallow water and subaerial vegetation.

Code Number and Title (GIS FIELD)	*Value*	*GIS Code Symbol*	*Map or Code-String Symbol*	*Comments*
CODE NO. 12 COLLAPSED LANDSCAPE OR LANDFORM (COLLAPSD12)				This code refers to a **Landform** or **Landscape** that had a core of glacial ice that subsequently melted and "let down" the overlying material.
	No Distinction Made	NO_DIST	*	
	Not Collapsed	NO_COLL	N	
	Collapsed	COLLAPSE	C	
CODE NO. 13 ERODED LANDSCAPE OR LANDFORM (ERODED13)				This code refers primarily to soil erosion that post-dates landform or landscape development.
	Not Present or No Distinction Made	NO_DIST	*	
	Eroded	ERODED	E	This value is used for areas of mappable size at a scale of 1:24,000 that show field, air photo, or soil mapping evidence of being eroded. The value may include relatively steep **Hillslopes.**
	Erosion Complex	EROSION_C	EC	This value is used for areas characterized by either intricately interfingered, or very small discontinuous areas, of eroded and non-eroded areas that individually are of unmappable size at a scale of 1:24,000, based on field, air photo, or soil mapping evidence.
	Iowan Erosion Surface	IOWAN	O	See Hallberg et al. (1978). Soil erosion that formed the Iowan Erosion Surface formed a **Landscape** of one or more erosional "steps" on interfluves in specific parts of the state.

MATERIAL AND MATERIAL SEQUENCE FIELD CODES

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 14 POST-GLACIAL LITHOSTRATIGRAPHIC UNIT (PSTGLACU14)				This code is to be used when sufficient information is available to informally or formally name post-glacial fluvial, lacustrine, peatland, and eolian formations.
	No Distinction Made	NO_DIST	*	
CODE NO. 15 TEXTURE AND TEXTURE SEQUENCE OF NEAR-SURFACE MATERIAL (TEXTURE15)				This code only applies to the upper 2 m of material, including any **Overlying Deposits.** Two systems are represented, a general one that differentiates by fine, coarse and peat/organic muck textures, and a more specific one that differentiates by USDA NRCS soil textures. Only one of these systems can be used for each **Landform** or **Landscape**, depending on the amount and reliability of subsurface information available.
General	Variable at this Scale, or No Distinction Made	NO_DIST	*	
	Peat or Organic Muck	P	P	
	Fine	F	F	This value includes silt and finer material. It may include loam and clay loam, depending on the region being mapped.
	Thinly Bedded Fines	Y	Y	
	Fine over Peat	F/P	FP	
	Coarse	CO	CO	This value includes sandy loam and coarser material. It may include loam and clay loam, depending on the region being mapped.
	Peat or Organic Muck over Fine	P/F	PF	
	Peat or Organic Muck over Coarse	P/CO	PC	
	Peat or Organic Muck over Interstratified Coarse and Fine	P/INTR_C&F	PQ	
	Interstratified Peat or Organic Muck and Fines	INTR_P&F	IPF	
	Discontinuous Peat or Organic Muck over Fine	DIS_P/F	PFN	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Discontinuous Peat or Organic Muck over Coarse	DIS_P/CO	PCR	
	Fine over Coarse	F/CO	FC	
	Fine over Interstratified Coarse and Fine	F/INTR_C&F	FQ	
	Coarse over Fine	CO/F	CF	
USDA NRCS	Clay	CY	CY	
	Silty Clay	SICY	SIC	
	Silty Clay Loam	SICYL	SICL	
	Silt Loam	SIL	SIL	
	Silt	SI	SI	
	Loam	L	L	
	Clay Loam	CYL	CL	
	Sandy Clay Loam	SACYL	SCL	
	Sandy Loam	SAL	SL	
	Loamy Sand	LSA	LS	
	Sand	SA	S	
	Gravel	G	G	
	Cobble	COB	B	
	Peat or Organic Muck over Clay to Silt Loam	P/CY-SIL	P/C-SIL	
	Peat or Organic Muck over Silty Clay	P/SICY	P/SIC	
	Peat or Organic Muck over Silty Clay and Sandy Gravel	P/SICY&SAG	P/SICG	
	Peat or Organic Muck over Silty Clay Loam over Clay Loam	P/SICYL/CYL	P/SICL/CL	
	Peat or Organic Muck to Silty Clay Loam over Sandy Loam to Sand	P-SICYL/SAL-SA	P-SICL/SL-S	
	Peat or Organic Muck over Clay Loam to Sandy Loam	P/CYL-SAL	P/CL-SL	
	Peat or Organic Muck over Clay Loam to Loamy Sand	P/CYL-LSA	P/CL-LS	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Peat or Organic Muck over Silty Clay Loam to Sandy Loam over Sand and Gravel	P/SICYL-SAL/SA&G	P/SICL-SL/S&G	
	Peat or Organic Muck over Silt Loam over Loam	P/SIL/L	P/SIL/L	
	Peat or Organic Muck over Silt Loam to Sand	P/SIL-SA	P/SIL-S	
	Peat or Organic Muck over Silt Loam over Loam to Sandy Loam	P/SIL/L-SAL	P/SIL/L-SL	
	Peat or Organic Muck over Silt Loam over Sandy Loam to Sand	P/SIL/SAL-SA	P/SIL/SL-S	
	Peat or Organic Muck over Silt over Sandy Loam	P/SI/SAL	P/SI/SL	
	Peat or Organic Muck to Silt over Sandy Loam to Sand	P-SI/SAL-SA	P-SI/SL-S	
	Peat or Organic Muck to Silt over Sandy Loam to Sand and Gravel	P-SI/SAL-SA&G	P-SI/SL-S&G	
	Peat or Organic Muck to Silt over Loamy Sand	P-SI/LSA	P-SI/LS	
	Peat or Organic Muck to Silt over Loamy Sand to Sand and Gravel	P-SI/LSA-SA&G	P-SI/LS-S&G	
	Peat or Organic Muck to Silt over Sand and Gravel	P-SI/SA&G	P-SI/S&G	
	Peat or Organic Muck over Loam	P/L	P/L	
	Peat or Organic Muck over Loam to	P/L-LSA	P/L-LS	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Loamy Sand			
	Peat or Organic Muck over Loam to Sand	P/L-SA	P/L-S	
	Peat or Organic Muck over Sandy Loam	P/SAL	P/SL	
	Peat or Organic Muck over Sandy Loam to Clay Loam	P/SAL-CYL	P/SL-CL	
	Peat or Organic Muck over Sandy Loam to Sand	P/SAL-SA	P/SL-S	
	Peat or Organic Muck over Loamy Sand over Loam	P/LSA/L	P/LS/L	
	Peat or Organic Muck over Loamy Sand	P/LSA	P/LS	
	Peat or Organic Muck over Loamy Sand over Sand and Gravel	P/LSA/SA&G	P/LS/S&G	
	Peat or Organic Muck over Loamy Sand to Sand	P/LSA-SA	P/LS-S	
	Peat or Organic Muck over Loamy Sand to Sand and Gravel	P/LSA-SA&G	P/LS-S&G	
	Peat or Organic Muck over Sand to Sandy Loam	P/SA-SAL	P/S-SL	
	Peat or Organic Muck over Sand over Loam to Clay Loam	P/SA/L-CYL	P/S/L-CL	
	Peat or Organic Muck over Sand	P/SA	P/S	
	Peat or Organic Muck over Sandy Gravel	P/SAG	P/SG	
	Interstratified Peat or Organic Muck and Sand	INTR_P&SA	IPS	
	Clay over Loam to Clay Loam	CY/L-CYL	C/L-CL	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Clay to Sandy Loam over Loam to Clay Loam	CY-SAL/L-CYL	C-SL/L-CL	
	Clay Loam to Sandy Loam	CYL-SAL	CL-SL	
	Clay Loam to Sandy Loam over Sand	CYL-SAL/SA	CL-SL/S	
	Clay Loam to Loamy Sand	CYL-LSA	CL-LS	
	Silty Clay to Coarse	SICY-CO	SIC-C	
	Silty Clay and Sandy Gravel	SICY&SAG	SIC&SG	
	Silty Clay Loam and Sand	SICYL&SA	SICL&S	
	Silty Clay Loam over Clay Loam	SICYL/CYL	SICL/CL	
	Silty Clay Loam over Clay Loam to Loam	SICYL/CYL-L	SICL/CL-L	
	Silty Clay Loam to Sandy Loam	SICYL-SAL	SICL-SL	
	Silty Clay Loam to Sandy Loam over Peat or Organic Muck over Sand and Gravel	SICYL-SAL/P/SA&G	SICL-SL/P/S&G	
	Silty Clay Loam to Sandy Loam over Sand	SICYL-SAL/SA	SICL-SL/S	
	Silty Clay Loam to Sandy Loam over Sand and Gravel	SICYL-SAL/SA&G	SICL-SL/S&G	
	Silty Clay Loam to Loamy Sand	SICYL-LSA	SICL-LS	
	Silty Clay Loam and Sandy Loam over Sand	SICYL-SAL/SA	SICL-SL/S	
	Silty Clay Loam to Sand	SICYL-SA	SICL-S	
	Silt Loam to Silty Clay Loam	SIL-SICYL	SIL-SICL	
	Silt Loam to Silty Clay Loam over Clay Loam	SIL-SICYL/CYL	SIL-SICL/CL	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Silt Loam to Loam	SIL-L	SIL-L	
	Silt Loam over Loam	SIL/L	SIL/L	
	Silt Loam over Loam to Sandy Loam	SIL/L-SAL	SIL/L-SL	
	Silt Loam over Loam to Loamy Sand over Sand	SIL/L-LSA/SA	SIL/L-LS/S	
	Silt Loam over Sandy Loam	SIL/SAL	SIL/SL	
	Silt Loam over Sandy Loam over Sandy Gravel	SIL/SAL/SAG	SIL/SL/SG	
	Silt Loam over Sandy Loam to Sand	SIL/SAL-S	SIL/SL-S	
	Silt Loam over Sand	SIL/SA	SIL/S	
	Loam to Clay Loam	L-CYL	L-CL	
	Loam to Silt Loam over Sand	L-SIL/SA	L-SIL/S	
	Loam to Sandy Loam	L-SAL	L-SL	
	Loam to Sandy Loam over Sand and Gravel	L-SAL/SA&G	L-SL/S&G	
	Loam to Loamy Sand	L-LSA	L-LS	
	Loam to Loamy Sand over Sand	L-LSA/SA	L-LS/S	
	Loam to Sand	L-SA	L-S	
	Loam to Sand and Gravel	L-SA&G	L-S&G	
	Loam over Clay Loam to Loam	L/CYL-L	L/CL-L	
	Loam over Sand	L/SA	L/S	
	Sandy Loam over Sand and Gravel	SAL/SA&G	SL/S&G	
	Sandy Loam over Gravelly Sand	SAL/GS	SL/GS	
	Sandy Loam over Sandy Clay Loam	SAL/SACYL	SL/SCL	
	Sandy Loam to Clay Loam	SAL-CYL	SL-CL	
	Sandy Loam over Sand	SAL/SA	SL/S	
	Sandy Loam over Sand and Gravel	SAL/S&G	SL/S&G	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Sandy Loam over Gravelly Sand	SAL/GSA	SL/GS	
	Sandy Loam over Gravel	SAL/G	SL/G	
	Sandy Loam to Loamy Sand over Gravelly Sand	SAL-LSA/GSA	SL-LS/GS	
	Sandy Loam to Sand	SAL-SA	SL-S	
	Sandy Loam to Sand and Gravel	SAL-SA&G	SL-S&G	
	Sandy Loam to Sand and Gravel over Sandy Loam to Loamy Sand	SAL-SA&G/SAL-LSA	SL-S&G/SL-LS	
	Loamy Sand over Loam	LSA/L	LS/L	
	Loamy Sand over Sand and Gravel	LSA/SA&G	LS/S&G	
	Loamy Sand over Gravelly Sand	LSA/GSA	LS/GS	
	Loamy Sand to Sand	LSA-SA	LS-S	
	Loamy Sand to Sand and Gravel	LSA-SA&G	LS-S&G	
	Sand to Sandy Loam	SA-SAL	S-SL	
	Sand to Sandy Loam over Clay Loam	SA-SAL/CYL	S-SL/CL	
	Sand to Sandy Loam over Loam to Clay Loam	SA-SAL/L-CYL	S-SL/L-CL	
	Sand over Sandy Clay Loam	SA/SACYL	S/SCL	
	Sand and Gravel	SA&G	S&G	
	Sandy Gravel	SAG	SG	
	Gravelly Sand	GSA	GSA	
	Etc.	Etc.	Etc.	Texture sequences can be added as necessary, separating the two texture map symbols by a backslash.
CODE NO. 16 DIAMICTON TEXTURE (DIAMICTN16)				Unsorted sediment ranging from clay to boulders deposited in very active environments. This code applies to uppermost lithologic value(s).
	No Distinction Made	NO_DIST	*	
	Diamicton Texture Not Present or	NO_DIA	O	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Uncommon Diamicton Texture	DIA	D	
CODE NO. 17 THICKNESS OF NEAR-SURFACE MATERIAL OVER BEDROCK OR GLACIAL DRIFT (THICKNSS17)				Use this code includes any thickness of material of **Overlying Deposits** in Code No. 18 in addition to the remaining underlying unconsolidated mostly non-glacial Quaternary materials. Thicknesses for some **Valley Margin** LsSA values consider the thickest part of these wedge-shaped landforms.
	No Distinction Made	NO_DIST	*	
	Not Present or <1m Thick, Laterally Discontinuous	ZERO	><	
	>2m Thick, Laterally Continuous	>2M	>>	
	<2m Thick, Laterally Continuous	<2M	<<	
	<2m, >1m Thick, Laterally Continuous	<2>1M	<>	
	>1m Thick, Laterally Continuous	>1M	>	
	<1m Thick, Laterally Continuous	<1M	<	
CODE NO. 18 OVERLYING DEPOSITS (OVERLDEP18)				"Overlying" refers to material usually <2m thick that was deposited on a **Landform** or **Landscape** sometime after the principal landform- or landscape-sediment assemblage developed. This deposit is not genetically related to the landform. Values under this code are applicable to any **Landform** or **Landscape**.
	Not Present	NO_PRES	N	
	No Distinction Made	NO_DIST	*	
	Type "o" Overbank Deposits	OVERO	O	This value is used where relatively very light tonal contrasts on aerial photography of valley areas are interpreted as overbank deposits that are likely to include, or field evidence indicates, deposition of significant post-settlement alluvium. Here "significant" means a sufficient thickness to obscure prehistoric cultural deposits. In plowed areas this typically means >0.27 m thick. In unplowed areas, it may be thinner. If not otherwise noted, presence is implied with **Floodplain Type "w"**.
	Type "a" Overbank	OVERA	A	This value is used where relatively light tonal contrasts on aerial photography

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Deposits			of valley areas are interpreted as overbank deposits. They may or may not include significant post-settlement alluvium.
	Sheetflood Deposits, Undifferentiated	SHEET	S	
	Hillslope Colluvium; Biomantle	HILL_COLLUV	H	This value is usually applied to upland landscapes. It includes the range of recognizable products from the combination of upland hillslope erosional, depositional, and soil evolution processes. See Johnson (1990).
	Loess	LOESS	L	
	Glaciolacustrine	GLA_LK	GL	Thick (>2m) **Glaciolacustrine** sediment mantles may occur in some **Outwash** or other depressional settings, and could have been interpreted as a **Glaciolacustrine Plain**, except for the dominant geologic process that shaped the landform.
	Outwash	OUTWASH	OU	Thick (>2m) **Outwash** mantles may occur in some **Glaciolacustrine** or other depressional settings, and could have been interpreted as an **Outwash Plain**, except for the dominant geologic process that shaped the landform.
	Eolian Sand Sheet, Discontinuous	EOL_SAND	E;	Discontinuous dunes and/or sheet sand.
	Wetland	WET_LAC	W	This value is for organic wetland deposits, with or without interbedded lacustrine or glaciolacustrine deposits, and is usually associated with **Depressions**.
	Till	TILL	T	Till, undifferentiated
CODE NO. 19 BURIED SOILS (BURSOIL19)				Documented or interpreted **Buried Soil**(s) are present, including consideration of **Overlying Deposits**. As used here, **Buried Soil** definition may include thick cumulic soils. The definition of **Buried Soil** does not have the depth limitations imposed by the USDA NRCS definition of **Buried Soil**.
	No Distinction Made	NO_DIST	*	
	Buried Soil(s) Not Present or Uncommon	NO_BUR_SOL	O	
	Buried Soil(s) Commonly Present	BUR_SOL	B	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 20 BASEMENT MATERIAL (BASEMENT20)				
	Not Exposed Within 2m of Ground Surface, or No Distinction Made	NO_DIST	*	
	Bedrock, Undifferentiated	BEDROCK	B	
	Thin Glacial Drift over Bedrock	DRIFT_BED	GB	
	Bedrock or Glacial Drift, Undifferentiated	BEDR_GLAC	K	
	Bedrock, Igneous	IGNEOUS	IG	
	Bedrock, Metamorphic	METAM	M	
	Bedrock, Sedimentary	SEDIM	S	
	Bedrock, Carbonate	CARBONATE	SC	
	Glacial Drift, Undifferentiated	GLACIAL	G	
	Glaciolacustrine Deposits	GLA_LAKE	L	
	Glaciofluvial Deposits	OUTWASH	O	
	Till	TILL	T	
	Thin Glaciofluvial over Glacial Drift or Bedrock	OUT_DRIFT	OK	
CODE NO. 21 BASEMENT MATERIAL IDENTIFIER (BSMNT_ID21)				This code consists of the lithology or lithostratigraphic name of the material underlying the material of interest. It is to be developed as needed.
	No Distinction Made	NO_DIST	*	
	Sherack Formation	SHERACK	S	
	Sherack and Poplar River Formations	SHERACK_POPLAR	SP	
	Cromwell Formation	CROM	CR	
	Duluth Complex	DULUTH	DC	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Ely Greenstone	ELY_GRE	EG	
	Banded Iron Fm.	IRON	FE	
	Giants Range Granite	GIANTS	GI	
	North Shore Volcanic Group	NS_VOLCAN	NS	
	Rove Fm.	ROVE	RO	
	Saganaga Granite	SAGANAGA	SG	
	Trommald Fm.	TROMMALD	TR	
	Vermillion Granite	VERMILLION	VG	

TEMPORAL FIELD CODES

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 22 STAGE OR SUBSTAGE OF LANDFORM-SEDIMENT ASSEMBLAGE (STG_LFSA22)				This code consists of the primary stage or substage of a **Landform**. It ignores minor younger surface modifications. See text regarding stage definitions. Additional temporal sequences can be added as necessary, separating the two stage or substage symbols by a hyphen.
	No Distinction Made	NO_DIST	*	
	Pre-Wisconsinan	PRE_WISC	P	
	Wisconsinan, Undifferentiated	WISC	W	
	Late Wisconsinan	L_WISC	LW	
	Late Wisconsinan to Holocene	L_WISC-HOL	LW-H	
	Late Wisconsinan to Early Holocene	L_WISC-E_HOL	LW-E	
	Late Wisconsinan to Late Holocene	L_WISC-L_HOL	LW-L	
	Late Wisconsinan to Historic	L_WISC-HIST	LW-S	
	Holocene, Undifferentiated	HOL_UNDIFF	U	This code may or may not include all the substages of the Holocene.
	Holocene	HOL	H	This code includes the Historic substage.
	Holocene to Historic	HOL-HIST	H-S	
	Early Holocene	E_HOL	E	
	Early to Middle Holocene	E_HOL-M_HOL	E-M	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Early to Late Holocene	E_HOL-L_HOL	E-L	
	Early Holocene to Historic	E-HOL-HIST	E-S	
	Middle Holocene	M_HOL	M	
	Middle to Late Holocene	M_HOL-L_HOL	M-L	
	Middle Holocene to Historic	M_HOL-HIST	M-S	
	Late Holocene	L_HOL	L	
	Late Holocene to Historic	L_HOL-HIST	L-S	
	Historic	HIST	S	
CODE NO. 23 STAGE OF OVERLYING DEPOSITS (STGOVRDP23)				This code consists of the stage of deposition of **Overlying Deposits** of Code No. 18. See text regarding stage definitions. Additional temporal sequences can be added as necessary, separating the two stage or substage symbols by a hyphen.
	Not Relevant or No Distinction Made	NO_DIST	*	
	Pre-Wisconsinan	PRE_WISC	P	
	Wisconsinan, Undifferentiated	WISC	W	
	Late Wisconsinan	L_WISC	LW	
	Late Wisconsinan to Holocene	L_WISC-HOL	LW-H	
	Late Wisconsinan to Early Holocene	L_WISC-E_HOL	LW-E	
	Late Wisconsinan to Historic	L_WISC-HIST	LW-S	
	Holocene, Undifferentiated	HOL_UNDIFF	U	This code may or may not include all the substages of the Holocene.
	Holocene	HOL	H	This code includes the Historic substage.
	Early Holocene	E_HOL	E	
	Early to Middle Holocene	E_HOL-M_HOL	E-M	
	Early to Late Holocene	E_HOL-L_HOL	E-L	
	Early Holocene to Historic	E-HOL-HIST	E-S	
	Middle Holocene	M_HOL	M	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	Middle to Late Holocene	M_HOL-L_HOL	M-L	
	Middle Holocene to Historic	M_HOL-HIST	M-S	
	Late Holocene	L_HOL	L	
	Late Holocene to Historic	L_HOL-HIST	L-S	
	Historic	HIST	S	

Code Number and Title	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 24 GLACIAL LAKE OR GLACIAL ICE PHASE (GLACPHAS24)				This code consists of recognized glacial ice and lake phases for the stratigraphically highest basement material
	No Distinction Made	NO_DIST	*	
Glacial Lake Phase				
	Cass	CASS	CS	
	Emerson	EMER	EM	
	Lockhart	LOCK	LO	
	Moorhead	MOOR	MO	
	Nipigon	NIPI	NI	
Glacial Ice Phase				
	Automba	AUTO	AU	
	Culver	CULV	CU	
	Duluth	DULU	DU	
	Hewitt	HEWI	HE	
	Itasca	ITAS	IT	
	Nickerson	NICK	NI	
	Pine City	PINE	PI	
	Split Rock	SPLI	SP	
	St. Croix	STCR	ST	
	St. Croix - Automba	STCR_AUTO	ST-AU	Superior lobe tills possibly representing both the Automba and St. Croix phases and that are either indistinguishable from each other, or are found in an interspersed mosaic pattern that is too fine to distinguish at the current mapping scale.

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 25 RELATIVE AGE OF GEOMORPHIC UNIT WITHIN A LANDFORM DEFINED BY CODE 7 (AGE_INLF25)				Most commonly refers to **Terraces** or **Wave-Cut Platforms**. A **Paleochannel**'s relative age refers to its associated **Terrace**'s relative age and not to the cross-cutting relations among these channels.
	No Distinction Made	NO_DIST	*	
	Youngest	YOUNG	1	
	Next to Youngest	YOUNG+1	2	
	Second Next to Youngest	YOUNG+2	3	
	Third Next to Youngest	YOUNG+3	4	
	Fourth Next to Youngest	YOUNG+4	5	
	Etc.	Etc.	Etc.	
CODE NO. 26 RELATIVE AGE OF GEOMORPHIC UNIT WITHIN A LANDFORM SUBDIVISION AS DEFINED IN CODE 9 (AGE_INSB26)				
	No Distinction Made	NO_DIST	*	
	Youngest	YOUNG	1	
	Next to Youngest	YOUNG+1	2	
	Second Next to Youngest	YOUNG+2	3	
	Third Next to Youngest	YOUNG+3	4	
	Fourth Next to Youngest	YOUNG+4	5	
	Etc.	Etc.	Etc.	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 27 RELATIVE AGE OF LANDFORM-SEDIMENT ASSEMBLAGE TO OTHER LANDSCAPE- OR LANDFORM-SEDIMENT ASSEMBLAGES (RLAGELSA27)				
	No Distinction Made	NO_DIST	*	
	Overlying, Crosscutting or Interfingering with Active Ice LsSA	A_ACT_ICE	I	
	Overlying, Crosscutting or Interfingering with Stagnant Ice LsSA	A_STAG_ICE	S	
	Overlying, Crosscutting or Interfingering with Ice Contact LsSA	A_ICE_CONT	N	
	Overlying, Crosscutting or Interfingering with Pediment LsSA	A_PEDIMENT	P	
	Overlying, Crosscutting or Interfingering with Glaciofluvial LsSA	A_OUTWASH	O	
	Overlying, Crosscutting or Interfingering with Catastrophic Flood LsSA	A_CAT_FLOOD	C	
	Overlying, Crosscutting or Interfingering with Glaciolacustrine LsSA	A_GLAC_LAC	A	
	Overlying, Crosscutting or Interfingering with Paleo-Valley LsSA	A_PALEO_VAL	Y	
	Overlying, Crosscutting or Interfingering with Peatland LsSA	A_PEAT	B	
	Overlying, Crosscutting	A_VAL_TERR	V	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
	or Interfingering with Valley Terrace LsSA			
	Overlying, Crosscutting or Interfingering with Floodplain LsSA	A_FLOOD	F	
	Overlying, Crosscutting or Interfingering with Valley Margin LsSA	A_VAL_MARG	M	
	Overlying, Crosscutting or Interfingering with Eolian LsSA	A_EOLIAN	E	
	Overlying, Crosscutting or Interfingering with Lacustrine LsSA	A_LAKE	L	
	Overlying, Crosscutting or Interfingering with [LfSA as necessary]	Etc.	Etc.	
CODE NO. 28 GEOCHRONOLOGY OF LfSA: LESS THAN OR EQUAL TO (GEOCHNLT28)				This code consists of a number interpreted from one or more radiocarbon ages, in uncorrected radiocarbon years before present, for a **Landform-Sediment Assemblage**. The code will continue to be developed and refined as more radiocarbon ages become available. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made	NO_DIST	*	
	12,000 B.P.	12000	1200	
CODE NO. 29 GEOCHRONOLOGY OF LfSA: GREATER THAN OR EQUAL TO (GEOCHNGT29)				This code consists of a number interpreted from one or more radiocarbon ages, in uncorrected radiocarbon years before present, for a **Landform-Sediment Assemblage**. The code will continue to be developed and refined as more radiocarbon ages become available. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made	NO_DIST	*	
	Present	0	0	
				This code consists of a number interpreted from one or more radiocarbon

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 30 GEOCHRONOLOGY OF OVERLYING DEPOSITS: LESS THAN OR EQUAL TO (O_CHRNLT30)				ages, in uncorrected radiocarbon years before present, for **Overlying Deposits**. The code will continue to be developed and refined as more radiocarbon ages become available. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made 12,000	NO_DIST 12000	* 1200	
CODE NO. 31 GEOCHRONOLOGY OF OVERLYING DEPOSITS GREATER THAN OR EQUAL TO (O_CHRNGT31)				This code consists of a number interpreted from one or more radiocarbon ages, in uncorrected radiocarbon years before present, for **Overlying Deposits**. The code will continue to be developed and refined as more radiocarbon ages become available. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made Present	NO_DIST 0	* 0	
CODE NO. 32 GEOCHRONOLOGY OF BASEMENT MATERIAL: LESS THAN OR EQUAL TO (BSMCHRLT32)				This code consists of a number interpreted from one or more radiocarbon ages, in uncorrected radiocarbon years before present, for **Basement Material**. The code will continue to be developed and refined as more radiocarbon ages become available. **Basement Material** may have the same **Geochronology** as the LfSA **Geochronology** if the **Basement Material** is part of the LfSA. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made	NO_DIST	*	

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
CODE NO. 33 GEOCHRONOLOGY OF BASEMENT MATERIAL: GREATER THAN OR EQUAL TO (BSMCHRGT33)				This code consists of a number interpreted from one or more radiocarbon ages, in uncorrected radiocarbon years before present, for **Basement Material**. The code will continue to be developed and refined as more radiocarbon ages become available. The **Basement Material** may have the same **Geochronology** as the LfSA **Geochronology** if the **Basement Material** is part of the LfSA. The Map Code has dropped the "ten's" off the years to abbreviate for mapping.
	No Distinction Made	NO_DIST	*	
	12,000	12000	1200	
Geologic Age of Surface (AGE_0M)				Whether the age of the LfSA surface falls within or without the recognized time span that Pre-Contact peoples lived in Minnesota (i.e., 12,500-200 B.P.).
	Outside the valid time span	0		
	Within the valid time span	1		
Geologic Age from Surface to 1 meter depth (AGE_0_1M)				Whether the age of the LfSA from the surface to one meter below the surface falls within or without the recognized time span that Pre-Contact peoples lived in Minnesota (i.e., 12,500-200 B.P.).
	Outside the valid time span	0		
	Within the valid time span	1		
Geologic Age from 1 meter to 2 meter depth (AGE_1_2M)				Whether the age of the LfSA from one meter below the surface to two meters below the surface falls within or without the recognized time span that Pre-Contact peoples lived in Minnesota (i.e., 12,500-200 B.P.).
	Outside the valid time span	0		
	Within the valid time span	1		
Geologic Age from 2 meter to 5 meter depth (AGE_2_5M)				Whether the age of the LfSA from two meters below the surface to five meters below the surface falls within or without the recognized time span that Pre-Contact peoples lived in Minnesota (i.e., 12,500-200 B.P.).
	Outside the valid time span	0		
	Within the valid time span	1		

Code Number and Title (GIS FIELD)	Value	GIS Code Symbol	Map or Code-String Symbol	Comments
Post-Depositional Environment at LfSA Surface (P_DEPO_0M)				Whether the land surface has been disturbed such that in situ prehistoric cultural deposits would or would not have been preserved. Does not consider plowed surfaces.
	Disturbed	0		
	Undisturbed	1		
Depositional Environment from 0 to 1 Meter Depth (DEPO_0_1M)				Estimate of the degree to which the energy conditions and other factors would have affected landscape suitability for occupation and preservation of prehistoric cultural deposits.
	Unsuitable	0		
	Low suitability	1		
	Moderate suitability	2		
	High suitability	3		
Depositional Environment from 1 to 2 Meter Depth (DEPO_1_2M)				Estimate of the degree to which the energy conditions and other factors would have affected landscape suitability for occupation and preservation of prehistoric cultural deposits.
	Unsuitable	0		
	Low suitability	1		
	Moderate suitability	2		
	High suitability	3		

Depositional Environment from 2 to 5 Meter Depth (DEPO_2_5M)			Estimate of the degree to which the energy conditions and other factors would have affected landscape suitability for occupation and preservation of prehistoric cultural deposits.
	Unsuitable	0	
	Low suitability	1	
	Moderate suitability	2	
	High suitability	3	
Landscape Suitability Rating at Surface (LSR_0M)			Suitability of the landscape surface to contain prehistoric cultural deposits. A product of surface geologic age (AGE_0M) and post-depositional environment (P_DEPO_0M)
	Unsuitable	0	
	Low suitability	1	
Landscape Suitability Rating at 0 to 1 Meter Depth (LSR_0_1M)			Suitability of the 0-1 meter depth to contain prehistoric cultural deposits. A product of surface geologic age (AGE_0_1M) and depositional environment (DEPO_0_1M)
	Unsuitable	0	
	Low suitability	1	
	Moderate suitability	2	
	High suitability	3	
Landscape Suitability Rating at 1 to 2 Meter Depth (LSR_1_2M)			Suitability of the 1-2 meter depth to contain prehistoric cultural deposits. A product of surface geologic age (AGE_1_2M) and depositional environment (DEPO_1_2M)
	Unsuitable	0	
	Low suitability	1	
	Moderate suitability	2	
	High suitability	3	
Landscape Suitability Rating at 2 to 5 Meter Depth (LSR_2_5M)			Suitability of the 2-5 meter depth to contain prehistoric cultural deposits. A product of surface geologic age (AGE_2_5M) and depositional environment (DEPO_2_5M)
	Unsuitable	0	
	Low suitability	1	
	Moderate suitability	2	
	High suitability	3	

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Appendix D

Core Logs

Core/Profile: 10DK01 (SB-01)
Location: 145th Street East (Dakota County Rd 42) approximately 2000 feet west of Emory Avenue East intersection
Legal description: NW SE Section 29 T115N R18W
Latitude/Longitude: 44.38598322970/-93.00334969430 (WGS84 horizontal datum)
County: Dakota
Parent material: Glaciofluvial
Vegetation: Grass
Slope: 2-5%
Elevation: 841.3 feet (256.4 meters)
Remarks: Hollow-stem auger and discontinuous spoon sampling; site photos.

Depth meters (ft)	Horizon or Zone	Description
1.21-1.62 (4.0-5.3)	C	brown (7.5YR5/4-4/4) fine to medium sand; few coarse faint dark brown (7.5YR3/2) mottles; faint thin to medium bedding; loose; non-effervescent; unknown lower boundary.
2.74-3.35 (9.0-11.0)	C	Optical Spectral Luminescence (OSL) tube collected – bottom of tube displays yellowish brown (10YR5/4) medium to coarse sand; single grain; loose; 35,460 +/- 180 years OSL age (UIC-2767)
4.28-4.62 (14.0-15.2)	C	brown to yellowish brown (10YR5/3-5/4) medium to coarse sand with pebbles; few coarse distinct strong brown (7.5YR5/6) mottles; medium bedding; loose; strong effervescence; abrupt lower boundary; mottles at lower boundary; pebbles are both exotic and local, subangular to subrounded and up to 3x3x3 cm in size.
4.62-4.77 (15.2-15.7)	C	brown to dark brown (7.5YR4/4-3/4) sandy clay loam diamicton; massive; extremely firm; strong effervescence; unknown lower boundary; collected "charcoal" micro-fragment at 472.4 cm (15.5 ft) that exceeded the laboratory's oldest limits of radiocarbon dating (>43,500 B.P.; Beta-279895); examined another similar micro-fragment under a SEM after the radiocarbon date was returned, and it was coal; glacial till.
5.79-6.17 (19.0-20.3)	Cg	very dark gray (2.5Y3/0-5Y3/1) sandy clay loam diamicton; massive, extremely firm, strong effervescence; collected sample; glacial till.
7.32-7.83 (24.0-25.7)	Cg	same as above; collected 741- 783 cm (24.3-25.2 ft.)
8.84-9.28 (29.0-30.5)	Cg	same as above; collected 890-927 cm (29.2-30.4 ft.)
10.36-10.85 (34.0-35.6)	Cg	same as above (kept unsplit sample; checked both ends); spoon cut through coarse cobble clasts at 1067-1070 cm (35.0-35.1 ft).
11.89-12.36 (39.0-40.6)	Cg	same as above; collected.
13.41-14.02 (44.0-46.0)	Cg	same as above except very dark gray (5Y3/1); collected 1344-1402 cm (44.1-46.0 ft).
14.94-15.53 (49.0-51.0)	Cg	same as above except many coarse gray shale fragments.
16.45-16.62 (54.0-54.6)	C	brown (7.5YR5/4) sandy clay loam to sandy loam diamicton; common fine prominent grayish brown (2.5Y5/2) and many fine distinct strong brown to yellowish red (5YR-7.5YR5/8) mottles; massive to thinly bedded at lower boundary; extremely firm; strong effervescence; abrupt, planar, angular lower boundary; coarsening downward; 5 photos; collected all.
16.63-17.07 (54.6-56.0)	C	yellowish brown (10YR5/6-5/8) medium to coarse sand with few fine pebbles; single grain; loose; slight effervescence; unknown lower boundary; wet.
17.98-18.59 (59.0-61.0)	C	Optical Spectral Luminescence (OSL) tube bottom of tube same as above except with common fine pebbles; strong effervescence; 176,540 +/- 17,350 OSL years (UIC-2766).
19.51-19.92 (64.0-65.4)	C	yellowish brown (10YR5/4-5/6) fine to coarse and coarse sands; medium bedding; loose; slight to strong effervescence; abrupt lower boundary.
19.92-20.07 (65.4-65.9)	C	yellowish brown to brownish yellow (10YR5/4-6/6) fine sand with pebbles; few medium distinct light gray (10YR7/2) mottles that are weathered, disintegrating local bedrock clasts; single grain; loose; slight to strong

Depth meters (ft)	Horizon or Zone	Description
		effervescence; unknown lower boundary.
21.03-21.35 (69.0-70.1)	C	same as above except gradual lower boundary; may be part of fining-up sequence.
21.35-21.44 (70.1-70.4)	C	same as above except increasing pebble count and size downward; pebbles are both exotic and local and are mostly subangular up to 1x1x1 cm.; abrupt lower boundary marked by dark red (10R3/6) very thin, silty clay loam bed (non-effervescent).
21.44-21.55 (70.4-70.7)	C	yellowish brown (10YR5/4-5/6) pebbly sand; single grain; loose; strong effervescence; clear lower boundary.
21.55-21.64 (70.7-71.0)	C	same as above except pebbly fine sandy loam, unknown lower boundary; sample collected.
22.56-22.59 (74.0-74.1)	C	yellowish brown (10YR5/4) very coarse sand; single grain; loose; strong effervescence; abrupt lower boundary.
22.59-22.89 (74.1-75.1)	C	yellowish brown (10YR5/4-5/6) sandy clay loam diamicton; many coarse distinct strong brown (7.5YR5/8) and few fine prominent light gray (2.5Y7/0-7/2) mottles near upper boundary; massive; extremely firm, strong effervescence; unknown lower boundary; pebbles range from well rounded to subangular; collected sample; till.
24.08-24.38 (79.0-80.0)	C	same as above except lower boundary contains many medium to coarse prominent FeOx stains of dark reddish brown to dark red (2.5YR3/4-3/6) and with many local angular pebbles of various sizes; sample collected with the R-horizon below.
24.38 (80.0)	R	weathered CO_3 bedrock; non-effervescent; auger refused; photos and sample collected.
End of Boring @ 24.38 (80.0)		top of bedrock elevation is 232.0 m (761 ft.)

Core/Profile: 10DK02 (SB-02)
Location: Blaine Avenue & 210th Street West
Legal description: SW SW Section 25 T 114N R19W
Latitude/Longitude: 44.6482608854/-93.0550869705 (WGS84 horizontal datum)
County: Dakota
Parent material: Wetland Soils
Vegetation: Grass Sod
Slope: 2-5%
Elevation: 863.7 feet (263.2 meters)
Remarks: Site photo

Depth cm(ft)	Horizon or Zone	Description
0.0-27.4 (0.0-0.9)	Ap	black (N/0) muck; massive; friable; non-effervescent; clear lower boundary.
27.4-48.8 (0.9-1.6)	Oa	black (N/0) muck; faint bedding; friable; non-effervescent; abrupt lower boundary; may not be trustworthy for radiocarbon dating because of sod farm management practices; collected 30.5-48.8 cm (1.0-1.6 ft); not dated.
48.8-77.7 (1.6-2.6)	C	gray (5Y5/1) coarse silt loam; few coarse prominent black (N/0) mucky mottles near top; friable; non-effervescent; abrupt lower boundary; many rootlets from muck above; common strong brown (7.5YR5/6) mottles that buffer rootlets.
77.7-85.3 (2.6-2.8)	C	olive gray (5Y5/2) fine to medium sand; single grain; loose; non-effervescent; unknown lower boundary; deoxidized (?).
121.9-155. 5 (4.0-5.1)	C	same as above except gradual lower boundary.
155.5-201.2 (5.1-6.6)	C	yellowish brown to dark yellowish brown (10YR5/4-4/4) medium sand and fine to medium sand; common coarse faint strong brown to brown (7.5YR5/6-5/4) mottles; single grain; loose; non-effervescent; unknown lower boundary.
243.8-365.8 (8.0-12.0)	C	Optical Spectral Luminescence (OSL) tube – bottom of tube was dark brown to brown (7.5YR4/4-10YR5/3; wet) fine to medium sand; 28,210 +/- 3370 OSL age years (UIC-2755).
End of Boring @ 365.8 (12.0)		

Core/Profile: 10DK03 (SB-03)
Location: Akin Road and 212th Ave.
Legal description: NE NE Section 36 T114N R20W
Latitude/Longitude: 44.6450172131/-93.1567762095 (WGS84 horizontal datum)
County: Dakota
Parent material: Wetland
Vegetation: Canary Reed Grass
Slope: 1-3%
Elevation: 902.7 feet (275.1 meters)
Remarks: Wetland; 2-3 site photos and photos of peat horizon's lower boundary

Depth cm(ft)	Horizon or Zone	Description
0.0-21.3 (0.0-0.7)	Oe	black (N/0) mucky peat; slightly matted to massive; violent effervescence; abrupt angular lower boundary.
21.3-24.4 (0.7-0.8)	Lma	gray to dark gray (5Y5/1-4/1) silty marl; many fine distinct yellowish red (5YR4/6) mottles; massive; friable; violent effervescence; abrupt angular lower boundary; lacustrine; many whole and fragmented mollusks.
24.4-29.0 (0.8-1.0)	Oe	black (N/0) mucky peat that is slightly higher in Munsell value than horizon below; massive; friable; violent effervescence; abrupt lower boundary; many fine whole mollusks.
29.0-85.3 (1.0-2.8)	Oe	black (N/0) mucky peat; massive; friable; non-effervescent; no apparent mollusks, few rootlets.
121.9-130.0 (4.0-4.3)	Oe	as above except collected leafy plant matter for C-14; abrupt lower boundary; 1810 +/- 40 B.P (Beta-279897).
130.0-138.7 (4.3-4.6)	Oe	same as above except strong effervescence; also used for C-14 date together with horizon above.
138.7-167.6 (4.6-5.5)	Cg	very dark gray (5Y3/1) alternating silt loam and sandy loam; few coarse faint dark gray green (5G4/1) mottles; medium bedding; friable and loose; violent effervescence; abrupt lower boundary; coarse clam shell (2.5 cm diamter) at lower boundary; possible plant root fragments collected that belong to peat beds from horizons above.
167.6-234.7 (5.5-7.7)	Cg	very dark gray (5Y3/1) medium sand with pebbles; single grain; loose; non-effervescent; unknown lower boundary.
243.8-301.8 (8.0-9.9)	Cg	very dark gray (5Y3/1) alternating medium to coarse and medium sands with pebbles; medium bedding; loose; non-effervescent; unknown lower boundary; few dark greenish gray (5G3/1) thin silty clay loam lenses that are slightly effervescent; pebbles up to 3x1x1.5 cm.; single silty clay loam lens yielded C-14 age of 18,020 +/- 70 B.P. (Beta-279898).
365.8-487.7 (12.0-16.0)	Cg	Optical Spectral Luminescence (OSL) tube collected – bottom of tube is very dark gray (5Y3/1) pebbly medium sand with strong effervescence; 18,890 +/- 1635 OSL age years (UIC-2663).
End of Boring @ 487.7 (16.0)		

Core/Profile: 10DK04 (SB-04)
Location: Highview Avenue & 235[th] Street West
Legal description: NW NW Section 9 T113N R20W
Latitude/Longitude: 44.614229041/-93.2381190715 (WGS84 horizontal datum)
County: Dakota
Parent material: Wetland Soils
Vegetation: Marsh Grasses
Slope: 2-3%
Elevation: 962.1 feet (293.3 meters)
Remarks: Ground was too soft and wet to get to the deepest peats.

Depth cm(ft)	Horizon or Zone	Description
0.0-21.3 (0-0.7)	Oi	black (10YR2/1) fibric peat; matted; non-effervescent; abrupt lower boundary; supersaturated, poor recovery; gradually increasing sand downward within lowermost approximately 5 cm of peat horizon.
21.3-36.6 (0.7-1.2)	C	olive gray (2.5Y-5Y5/2; deoxidized) coarse silt loam; massive; friable; non-effervescent; unknown lower boundary; possibly lacustrine.
121.9-198.1 (4.0-6.5)		tube destroyed during advancement
198.1-243.8 (6.5-8.0)	C	brown (10YR-7.5YR5/2) coarse to very coarse sand with pebbles; single grain; loose; non-effervescent; unknown lower boundary; few thin pebble clast-supported beds, high energy environment that may be shoreline or fluvial; common subangular gray shale pebbles up to 1x2x3 cm; common CO_3 pebbles.
243.8-365.8 (8.0-12.0)	C	Optical Spectral Luminescence (OSL) tube collected – sample at bottom of barrel was medium to coarse sand that was the same as horizon above; OSL sample proved to be too coarse of texture for OSL date.
End of Boring @ 365.8 (12.0)		

Core/Profile: 10DK05 (SB-05)
Location: US Highway 61 & 190th Avenue
Legal description: SW SW Section 15 T114N R17W
Latitude/Longitude: 44.674390948/-92.8532896718 (WGS84 horizontal datum)
County: Dakota
Parent material: Fluvial deposits
Vegetation: Grass
Slope: 2-3%
Elevation: 818.1 feet (249.3 meters)
Remarks: Site photo

Depth cm(ft)	Horizon or Zone	Description
0.0-27.4 (0.0-0.9)	Ap1	black (10YR2/1) sandy loam; massive; loose; non-effervescent; clear lower boundary.
27.4-39.6 (0.9-1.3)	Ap2	very dark brown (10YR2/2) sandy loam to loamy sand; massive; loose; non-effervescent; clear lower boundary.
39.6-73.2 (1.3-2.4)	C	brown (7.5YR5/4) fine sand to loamy sand; few thin distinct black (10YR2/1) lenses; single grain to faint bedding; loose; non-effervescent; unknown lower boundary.
121.9-179.8 (4.0-5.9)	C	same as above except gradual lower boundary
179.8-204.2 (5.9-6.7)	C	brown to yellowish brown (7.5YR-10YR5/4) fine sand; few thin faint strong brown (7.5YR5/6) mottles; loose; non-effervescent; unknown lower boundary; rare black (N/0) thin to laminar Mn/Ox stains; well sorted.
243.8-365.8 (8.0-12.0)	C	Optical Spectral Luminescence (OSL) tube collected – sand at bottom same as horizon described above; 25,080 ± 1920 OSL age years (UIC-2754).
365.8-438.9 (12.0-14.4)	C	brown to yellowish brown (7.5YR-10YR5/4) fine to medium sand; common thin faint very dark grayish brown to very dark brown (10YR3/2-2/2) mottles; faint bedding; loose; non-effervescent; unknown lower boundary; rare thin to medium bed of medium to coarse sand.
487.7-566.9 (16.0-18.6)	C	same as above except few to common very thin medium to coarse sand beds within the sample's matrix.
609.6-612.7 (20.0-20.1)	C	same as above except medium sand and no medium to coarse sand beds; abrupt lower boundary.
612.7-646.2 (20.1-21.2)	C	same as above except fine sand; unknown lower boundary; photo collected.
731.5-853.4 (24.0-28.0)		Optical Spectral Luminescence (OSL) tube collected – medium well sorted sand at bottom of tube; non-effervescent; wet; 26,885 ± 3580 OSL age years (UIC-2764).
End of Boring @ 853.4 (28.0)		

Core/Profile: 10DK06 (SB-06)
Location: Minnesota Trunk Highway 316 & Sand Coulee
Legal description: SW NE Section 11 T114N R17W
Latitude/Longitude: 44.6959128403/-92.8211138241 (WGS84 horizontal datum)
County: Dakota
Parent material: Sand dune or alluvial levee
Vegetation: Grass
Slope: 5-9%
Elevation: 811.4 feet (247.3 meters)
Remarks: Road-cut; may not be the best option for dating the levee but other options were people's front yards or maybe the DNR Sand Coulee nature preserve.

Depth cm(ft)	Horizon or Zone	Description
0.0-3.1 (0.0-0.1)	Ap	black (10YR2/1) sandy loam; massive; very friable; non-effervescent; abrupt lower boundary.
3.1-18.3 (0.1-0.6)	CA	brown (7.5YR4/4) fine to medium sand; single grain; loose; non-effervescent; clear lower boundary; 1 large gravel clast of black basalt.
18.3-54.9 (0.6-1.8)	C	strong brown (7.5YR5/6) fine to medium sand; single grain; loose; non-effervescent; unknown lower boundary.
121.9-243.8 (4.0-8.0)	C	Optical Spectral Luminescence (OSL) tube collected – sample at bottom of tube was the same as horizon above except medium sand; 3,415 ± 350 OSL age years (UIC-2756).
End of Boring @ 243.8 (8.0)		

Core/Profile: 10DK07 (SB-07)
Location: 160[th] Street East (aka 31[st] St. E.) & Dakota County Road 91
Legal description: NE NE Section 2 T114N R17W
Latitude/Longitude: 44.7163795298/-92.8147400582 (WGS84 horizontal datum)
County: Dakota
Parent material: Fluvial deposits
Vegetation: Grass
Slope: 5-7%
Elevation: 822.2 feet (250.6 meters)
Remarks: Opposite side of 160[th] Street E. from driveway near east-southeast corner of T-intersection of two roads.

Depth cm(ft)	Horizon or Zone	Description
0.0-18.3 (0.0-0.6)	Ap1	dark yellowish brown (10YR3/4) loam; weak medium granular; very friable; non-effervescent; abrupt lower boundary; road-ditch fill.
18.3-33.5 (0.6-1.1)	Ap2	black (10YR2/1) loam; mottles are sediment clods worked up from next lower horizon; compacted thin platy structure; very friable; non-effervescent; abrupt lower boundary; road-ditch fill.
33.5-91.4 (1.1-3.0)	Ap3	dark brown (10YR3/3) sandy clay loam; many assorted mottle colors consisting of clods worked from horizons above and below; compacted thin platy structure; firm; non-effervescent; abrupt irregular lower boundary; stone-fill road base materials.
91.4-103.6 (3.0-3.4)	A	very dark brown (10YR2/2) loam to sandy loam; few fine distinct strong brown (7.5YR5/8) mottles; weak fine subangular blocky; firm; non-effervescent; unknown lower boundary; might also be fill or deformed strata.
121.9-137.2 (4.0-4.5)	AE	very dark brown (10YR2/2) loam; many medium distinct strong brown (7.5YR5/6) mottles; weak medium subangular blocky parting to medium thin platy; few thin discontinuous psilans; firm; non-effervescent; abrupt lower boundary.
137.2-164.6 (4.5-5.4)	CA	very dark brown (10YR2/2) sandy loam; common irregular distinct dark grayish brown (2.5Y2/2) mottles; massive; very friable; non-effervescent; gradual lower boundary.
164.6-228.6 (5.4-7.5)	C	very dark brown to very dark grayish brown (10YR2/2-3/2) loam to sandy loam; few thin distinct pale brown to brown (10YR6/3-5/3) mottles; laminar to massive; very friable; non-effervescent; unknown lower boundary; mottles are very thin to laminar lenses of very coarse silt loam.
243.8-249.9 (8.0-8.2)	C	same as above except gradual lower boundary.
249.9-274.3 (8.2-9.0)	C	brown to dark brown (7.5YR4/4-4/3) loam to sandy clay loam; laminar bedding; friable; non-effervescent; gradual lower boundary.
274.3-332.2 (9.0-10.9)	C	strong brown (7.5YR4/6) fine to medium loamy sand; few thin faint dark brown (7.5YR3/4) colored beds; thin faint bedding; loose; non-effervescent; unknown lower boundary; uppermost unit of the higher energy deposits described below.
365.8-487.7 (12.0-16.0)	C	Optical Spectral Luminescence (OSL) tube collected; gravel at bottom of tube; 38,180 ± 3815 years OSL age (UIC-2759).
487.7-501.4 (16.0-16.5)	C	dark yellowish brown to brown (10YR-7.5YR4/4) medium to coarse sand; single grain; loose; non-effervescent; abrupt lower boundary; fining-up sequence; pebble lag at lower boundary.
501.4-519.7 (16.5-17.1)	C	brown (7.5YR5/4) medium sand; thin bedding; loose; non-effervescent; abrupt lower boundary.
519.7-531.9 (17.1-17.5)	C	yellowish brown to dark yellowish brown (10YR5/6-4/6) coarse silt loam; massive; very friable; non-effervescent; clear lower boundary; possible loess.
531.9-560.8 (17.5-18.4)	C	brown (7.5YR5/4) very fine sand and very coarse silt loam; many very thin distinct black (10YR2/1) mottles; laminar and very thin cross-bedding and

Depth cm(ft)	Horizon or Zone	Description
		truncated cross-beds; loose; non-effervescent; abrupt lower boundary; low angle of repose on cross-beds; possible eolian deposit (photo and sample collected).
560.8-570.0 (18.4-18.7)	C	brown to light brown (7.5YR5/4-6/4) medium sand; faint bedding; loose; non-effervescent; unknown lower boundary; thin siltier lens at 565.4 cm (18.6 ft).
609.6-661.4 (20.0-21.7)	C	same as above except saturated; abrupt wavy lower boundary; MnOx staining at lower boundary.
661.4-670.6 (21.7-22.0)	C	yellowish brown (10YR5/4) coarse silt loam to very fine sandy loam; common coarse faint yellowish brown (10YR5/6-5/8) mottles; faint laminar to thin bedding; friable; non-effervescent; unknown lower boundary; faint traces of cross-bedding.
731.5-743.7 (24.0-24.4)	C	same as above except saturated; abrupt wavy lower boundary.
743.7-783.3 (24.4-25.7)	C	brown to yellowish brown (10YR5/3-5/4) medium sand; few medium and thin MnOx stains at slight textural changes; coarse yellowish brown (10YR5/6-5/8) color banding at lower boundary; faint bedding; loose; non-effervescent; abrupt lower boundary; thin very coarse sand bed at lower boundary.
End of Boring @850.4 (27.9)	R	refusal on CO_3 probable bedrock at 850.4 cm (27.9 ft).

Core/Profile: 10DK08 (SB-08)
Location: 160th Street East (aka 31st St. E.)
Legal description: NE NE Section 1 T114N R17W
Latitude/Longitude: 44.7166185125/-92.7967020748 (WGS84 horizontal datum)
County: Dakota
Parent material: Fluvial deposits
Vegetation: Grass
Slope: 3-5%
Elevation: 825.9 feet (251.7 meters)
Remarks:

Depth cm(ft)	Horizon or Zone	Description
0.0-15.2 (0.0-0.5)	Ap1	black (10YR2/1) loam; massive; friable; non-effervescent; abrupt lower boundary.
15.2-41.2 (0.5-1.4)	Ap2	black (10YR2/1) loam; weak thin platy; friable; non-effervescent; abrupt lower boundary.
41.2-54.9 (1.4-1.8)	AB	very dark gray to very dark grayish brown (10YR3/1-3/2) loam; weak thin platy; friable; non-effervescent; gradual lower boundary.
54.9-79.3 (1.8-2.6)	Bt	dark brown (7.5YR3/2-3/4) loam to silty clay loam; very weak medium subangular blocky; friable to firm; non-effervescent; clear lower boundary.
79.3-88.4 (2.6-2.9)	C	dark brown (7.5YR3/4) medium loamy sand; single grain; loose; non-effervescent; unknown lower boundary.
121.9-149.4 (4.0-4.9)	Bw	brown (7.5YR5/4) sandy clay loam diamicton with rounded exotic pebbles; weak subangular blocky parting to weak medium prisms; firm; non-effervescent; abrupt lower boundary.
149.4-167.6 (4.9-5.5)	C	strong brown (7.5YR5/6) fine to medium sand; single grain; loose; non-effervescent; abrupt lower boundary; well sorted.
167.6-182.9 (5.5-6.0)	Bw	same as 121.9-149.4 cm (4.0-4.9 ft) except many medium distinct gray (2.5Y5/1) mottles.
182.9-204.2 (6.0-6.7)	C	same as 149.4-167.6 cm (4.9-5.5 ft) above.
243.8-365.8 (8.0-12.0)	C	collected for Optical Spectral Luminescence – sand on both ends similar to above; unknown lower boundary; sample was undatable with OSL because of poor precision (UIC-2749).
365.8-432.8 (12.0-14.2)	C	brown (7.5YR5/4) fine to medium sand; faint finer textural banding to single grain; loose; non-effervescent; unknown lower boundary; well sorted; banding only apparent because of slightly moister conditions.
487.7-524.3 (16.0-17.2)	C	same as above except brown (10YR5/3); no apparent moister bands; medium to coarse sand with pebbles including a fine pebbly bed of exotics at 501.4 cm (16.5 ft).
End of Boring @ 548.6 (18.0)		Refusal at 548.6 cm (18.0 ft) on bedrock

Core/Profile: 10DK09 (SB-09)
Location: Orlando and 160th Street East (aka 31st St. E.)
Legal description: NW NW Section 6 T114N R16W
Latitude/Longitude: 44.7165751035/-92.7924742678 (WGS84 horizontal datum)
County: Dakota
Parent material: Fluvial sands
Vegetation: Grasses
Slope: 3-5%
Elevation: 847.1 feet (258.2 meters)
Remarks: Site photo collected

Depth cm(ft)	Horizon or Zone	Description
0.0-18.3 (0.0-0.6)	Ap1	black (10YR2/1) loam; few fine granular and weak thin platy; friable; non-effervescent; abrupt lower boundary.
18.3-42.7 (0.6-1.4)	Ap2	black (10YR2/1) loam; many fine distinct dark brown to strong brown (7.5YR3/4-4/6) mottles; friable; non-effervescent; gradual lower boundary.
42.7-85.3 (1.4-2.8)	C	dark brown to strong brown (7.5YR3/4-4/6) silt loam; common fine to coarse black (10YR2/1) mottles; massive; friable; non-effervescent; unknown lower boundary.
121.9-149.4 (4.0-4.9)	C	brown (7.5YR4/4) medium sand to loamy sand; crudely bedded; loose; non-effervescent; abrupt lower boundary.
149.4-185.9 (4.9-6.1)	CR	very pale brown (10YR8/2) weathered sandstone bedrock; few medium prominent strong brown (7.5YR5/6) mottles; bedded; hard; non-effervescent; unknown lower boundary; photo collected of 121.9-185.9 cm (4.0-6.1 ft) interval; recollected second core at 121.9-185.9 cm (4.0-6.1 ft) for Optical Spectral Luminescence sample; 17,680 ± 1540 OSL age years (UIC-2751)
185.9 (6.1)	R	Refused on bedrock at 185.9 cm (6.1 ft).

Core/Profile: 10DK10 (SB-10)
Location: Michael Avenue
Legal description: NE NE Section 10 T114N R17W
Latitude/Longitude: 44.6993209865/-92.8331237657 (WGS84 horizontal datum)
County: Dakota
Parent material: Fluvial deposits
Vegetation: Corn stubble
Slope: 2-3%
Elevation: 821.6 feet (250.4 meters)
Remarks: 2 site photos to the south; although the two OSL ages from this core are out of chronologic sequence, their standard deviations overlap from approximately 22,350 to 26,545 OSL age years, suggesting that if these dates are close to real time, then this sedimentary package was deposited more closely in time, possibly as one flood event.

Depth cm(ft)	Horizon or Zone	Description
0.0-27.4 (0.0-0.9)	Ap	black (10YR2/1) sandy loam; many mottles of various colors from both road and agricultural plowing; non-effervescent; clear lower boundary; plow zone in road right-of-way.
27.4-67.1 (0.9-2.2)	A	black (10YR2/1) sandy loam; massive; very friable; non-effervescent; clear lower boundary.
67.1-103.6 (2.2-3.4)	C	brown to strong brown (7.5YR4/4-5/6) fine sand; single grain; loose; non-effervescent; unknown lower boundary.
121.9-243.8 (4.0-8.0)	C	Optical Spectral Luminescence tube – top of tube may be sluff; bottom was brown (7.5YR-10YR5/4) medium to coarse sand with few pebbles; 25,420 ± 3,070 OSL age years (UIC-2762).
243.8-307.9 (8.0-10.1)	C	brown to yellowish brown (7.5YR-10YR5/4) medium to coarse sand; single grain to faint bedding; loose; non-effervescent; unknown lower boundary; few well-rounded exotic pebbles.
365.8-417.6 (12.0-13.7)	C	same as above
487.7-539.5 (16.0-17.7)	C	same as above
609.6-731.5 (20.0-24.0)	C	Optical Spectral Luminescence tube – top may be sluff; bottom was the same as horizon described above; sample yielded 21,995 ± 4,550 OSL age years (UIC-2761).
End of Boring @ 731.5 (24.0)		

Core/Profile: 10DK12 (SB-12)
Location: Ravenna Trail & Dakota County Road 68
Legal description: NW SE Section 21 T114N R16W
Latitude/Longitude: 44.6637019625/-92.7402485094 (WGS84 horizontal datum)
County: Dakota
Parent material: Alluvium
Vegetation: Grass
Slope: 0-2%
Elevation: 684.4 feet (208.6 meters)
Remarks: Roadside. One site photo

Depth cm(ft)	Horizon or Zone	Description
0.0-13.7 (0.0-0.5)	Ap	very dark grayish brown (10YR3/2) fine to medium sandy loam; common medium faint brown to dark brown (10YR4/3) mottles; massive; very friable; non-effervescent; abrupt lower boundary; fill or tilled.
13.7-39.6 (0.5-1.3)	C	brown to dark brown (10YR4/3) fine to very coarse pebbly sand; single grain and bedded; loose; non-effervescent; abrupt lower boundary; fining-up sequence.
39.6-91.4 (1.3-3.0)	C	black (10YR2/1) silt loam coarsening downward to medium sandy loam; few coarse distinct dark gray to dark grayish brown (2.4Y4/0-4/2) silt loam laminar beds at top boundary, otherwise mostly massive; friable to very friable; non-effervescent; unknown lower boundary; fining-up sequence.
121.9-125.0 (4.0-4.1)	C	very dark brown (10YR2/2) fine sandy loam coarsening downward to medium sandy loam; few coarse faint brown to dark brown (10YR4/3) mottles; massive; very friable; non-effervescent; abrupt lower boundary; fining-up sequence; wet.
125.0-149.4 (4.1-4.9)	C	brown to dark brown (10YR4/3) fine to coarse loamy sand; single grain; loose; non-effervescent; abrupt, irregular; fining-up sequence.
149.4-164.6 (4.9-5.4)	C	brown to dark brown (10YR4/3) loam; common medium faint dark gray to dark grayish brown (2.5Y4/0-4/2) mottles; massive; friable; non-effervescent; abrupt lower boundary.
164.6-192.0 (5.4-6.3)	C	dark yellowish brown (10YR4/4) very fine sandy loam; common coarse distinct dark gray to dark grayish brown (2/5Y4/0-4/2) mottles; massive; very friable; non-effervescent; unknown lower boundary.
243.8-304.8 (8.0-10.0)	C	same as above except dark brown (7.5YR3/2-3/4) and mottles are gray to grayish brown (2.5Y5/0-5/.2); abrupt lower boundary.
304.8-307.9 (10.0-10.1)	C	brown to dark brown (7.5YR4/4) sandy loam with pebbles; common coarse distinct dark gray to dark grayish brown (2.5Y4/0-4/2) mottles; single grain; very friable; non-effervescent; unknown lower boundary; many fine MnOx stains; well-rounded exotic pebbles up to 1x2x1.5 cm.
365.8-399.3 (12.0-13.1)	C	same as 243.8-304.8 cm (8.0-10.0 ft) above except very fine sandy loam to loam.
399.3-417.6 (13.1-13.7)	C	brown to dark brown (7.5YR4/2-4/4) very fine sandy loam; common coarse prominent dark reddish gray (2.5YR4/0) mottles; massive; friable; non-effervescent; unknown lower boundary; few thin medium to coarse sand beds.
487.7-509.0 (16.0-16.7)	C	yellowish brown to brown (10YR-7.5YR5/4) medium loamy sand; single grain; loose; non-effervescent; clear lower boundary.
509.0-560.8 (16.7-18.4)	C	yellowish brown to brown (10YR-7.5YR5/4) medium to very coarse sand with pebbles; few thin beds composed of very coarse sand; loose; non-effervescent; unknown lower boundary; overall one large fining-up sequence with occasional fluxes of higher energy to create thin beds of coarse grains higher in horizon
609.6-652.3 (20.0-21.4)	C	same as above (another fining-up sequence) but with no apparent thin beds of coarse sand; one CO_3 pebble (weathered).

Depth cm(ft)	Horizon or Zone	Description
731.5-759.0 (24.0-24.9)	C	dark grayish brown (10YR4/2) medium to coarse sand with pebbles; single grain; loose; non-effervescent; abrupt lower boundary.
759.0-786.4 (24.9-25.8)	C	brown to dark brown (10YR4/3) very fine to fine loamy sand with few pebbles; single coarse very dark brown (10YR2/2) mottle at 768.1 cm (25.2 ft); single grain and common thin bedding; loose; non-effervescent; unknown lower boundary; common coarse sand lenses (2 photos); pebbles are both CO_3 and exotics; collected darker stain at 768.1 cm (25.2 ft).
853.4-899.2 (28.0-29.5)	C	brown to dark brown (10YR4/3) fine sand coarsening downward to coarse sand; single grain; loose; non-effervescent; abrupt lower boundary; fining-up sequence.
899.2-912.9 (29.5-30.0)	C	brown to dark brown (10YR4/3) poorly sorted fine to coarse sand; single grain; loose; non-effervescent; abrupt lower boundary; exotic well rounded pebbles at lower boundary (lag).
912.9-923.5 (30.0-30.3)	C	brown to dark brown (10YR4/3) fine loamy sand; few organic stained laminar beds collected near top; faint laminar to thin bedding; very friable; non-effervescent; gradual lower boundary; top of fining-up sequence that continues from next lower horizon; organic stains yielded radiocarbon date of 9,770 ± 50 B.P. (Beta-279899).
923.5-957.1 (30.3-31.4)	C	brown to dark brown (10YR4/3) medium pebbly sand coarsening downward to very coarse pebbly sand; faint bedding; loose; non-effervescent; unknown lower boundary; bottom of fining-up sequence that continues upward into next horizon.
975.4-1072.9 (32.0-35.2)	C	same as horizon above except repeated 3 times in this core barrel sample.
1097.3-1219.2 (36.0-40.0)	C	Optical Spectral Luminescence sample (coarse sands the same as above were identified at the bottom of this sample barrel); sample yielded 5,300 ± 580 OSL age years (this age seems young for the current geological and landform interpretations; so it is possible that the soils either were exposed during road-cut construction, or did not have a well defined moisture content through history, which is critical for OSL dating).
1219.2-1258.8 (40.0-41.3)	C	brown to dark brown (10YR4/3-3/3) medium to coarse sand; single grain; loose; non-effervescent; unknown lower boundary.
1341.1-1405.1 (44.0-46.1)	C	brown to dark brown (10YR4/3) very coarse sand to gravel; single grain; loose; non-effervescent; unknown lower boundary; coarse fining-up sequence, many exotic well-rounded gravel up to 3x4x4.5 cm, gravels starts at 1371.6 cm (45.0 ft), very few angular CO_3 gravel.
1463.0- (48.0-) End of Boring @ 1463.04 (48.0)	C	gravels rejected the next sample core barrel.

Core/Profile: 10GD01 (SB-13)
Location: Ski Road (approximately 1 mile west of Frontenac Golf Course entrance)
Legal description: SE SW Section 8 T112N R13W
Latitude/Longitude: 44.5150857528/-92.4023947988 (WGS84 horizontal datum)
County: Goodhue
Parent material: Alluvium/Colluvium
Vegetation: Weeds
Slope: 9-12%
Elevation: 725.6 feet (221.2 meters)
Remarks: Mostly deoxidized sediment in this core. Three site photos after Soil Boring SB-15 photos.

Depth cm(ft)	Horizon or Zone	Description
0.0-27.4 (0.0-0.9)	Ap	roadfill; abrupt lower boundary.
27.4-57.9 (0.9-1.9)	C(Ap?)	very dark grayish brown (10YR3/2) silt loam to loam with pebbles; weathered and dissolving CO_3 pebbles; massive to crude bedding; friable; non-effervescent; abrupt lower boundary.
57.9-73.2 (1.9-2.4)	AC	black (10YR2/1) loam with fine pebbles; massive; very friable; non-effervescent; abrupt lower boundary.
73.2-83.8 (2.4-2.8)	C	dark brown (10YR3/3) loam; common fine faint black and yellowish brown (10YR2/1& 5/4) mottles; very friable; non-effervescent; unknown lower boundary; upper boundary has weathered CO_3 and sandstone cobbles.
121.9-207.3 (4.0-6.8)	C	dark brown (10YR3/3) loam; common coarse prominent reddish yellow (7.5YR6/6; weathered CO_3) and pinkish white (7.5YR8/2; weathered sandstone) mottles; very friable and loose; spotty effervescence; unknown lower boundary; interbedded loams and weathered cobbles of CO_3 and sandstone.
243.8-277.4 (8.0-9.1)	C	same as above except wet and common coarse distinct dark gray (2.5Y4/0) mottles; abrupt lower boundary.
277.4-292.6 (9.1-9.6)	C	light yellowish brown (10YR6/4) pebbly medium sand; few fine distinct yellowish brown (10YR5/6) mottles; single grain; loose; non-effervescent; unknown lower boundary; pebbles of local sedimentary rocks (some not as weathered as above); gully washer deposits from adjacent bluff, partially pebble clast supported and partially matrix-support.
365.8-.71-9 (12.0-12.2)	C	same as above except large cobble blocked tube, poor recovery.
487.7-563.9 (16.0-18.5)	C	alternating brown and brownish yellow (10YR5/3& 6/6) silty clay loam and pebbly sands and cobbles made from local bedrock; many coarse distinct brownish yellow (10YR6/8) mottles; crudely bedded (some beds have more pebbles and cobbles); very friable to loose; non-effervescent; unknown lower boundary; deoxidized colluvial slope or fan materials deposited under variable energies.
609.6-627.9 (20.0-20.6)	C	same as above
627.9-667.5 (20.6-21.9)	CR	cored through weathered sandstone boulder.
667.5-698.0 (21.9-22.9)	C	same as 487.7-563.9 cm (16.0-18.5 ft) above except refusal at 701.0 cm (23.0 ft) on bedrock or boulder; spotty effervescence.
End of Boring @ 698.0 (22.9)		

Core/Profile: 10GD02 (SB-14)
Location: 296th Street halfway between both intersections with U.S. Highway 61
Legal description: NW SE Section 9 T112N R13W
Latitude/Longitude: 44.5176794079/-92.3779395349 (WGS84 horizontal datum)
County: Goodhue
Parent material: Fill/alluvium/fan/wetland
Vegetation: Canary grass
Slope: 9-12%
Elevation: 701.3 feet (213.7 meters)
Remarks: Roadside ditch

Depth cm(ft)	Horizon or Zone	Description
0.0-33.5 (0.0-1.1)	Ap	very dark grayish brown (10YR3/2) silty clay loam; many various colored mottles; massive to irregular laminar bedding; firm; non-effervescent; clear lower boundary; disturbed.
33.5-45.7 (1.1-1.5)	OC	dark yellowish brown (10YR3/4) muck with silty clay loam; many fine grayish brown to light brownish gray (2.5Y5/2-6/2) mottles; laminar; soft; slight effervescence; clear lower boundary; few fine whole snails and common broken clams.
45.7-54.9 (1.5-1.8)	C	grayish brown to light brownish gray (2.5Y5/2-6/2) silt loam; many fine reddish yellow (7.5YR6/8) and N/0 (black) MnOx mottles; laminar; friable; slight effervescent; unknown lower boundary; fine whole snails and common broken clams.
121.9-140.2 (4.0-4.6)	C	as above except silt loam to silty clay loam.
140.2-170.7 (4.6-5.6)	C	grayish brown to dark grayish brown (2.5Y5/2-4/2) silt loam; many medium distinct strong brown (7.5YR4/6) mottles; laminar; friable; slight effervescence; gradual lower boundary; deoxidized horizon.
170.7-213.4 (5.6-7.0)	Cg	very dark gray (2.5Y3/0) silty clay loam; massive; very firm; spotty to slight downward effervescence; unknown lower boundary; uniform texture throughout; lacustrine; many mollusks (collected sample).
243.8-283.5 (8.0-9.3)	Cg	same as above except clear lower boundary.
283.5-310.9 (9.3-10.2)	C/Cg	alternating grayish brown and very dark gray (2.5Y5/2 & 3/0) silt loams; laminar to thinly bedded; friable; slight effervescence; unknown lower boundary; few rootlets.
365.8-410.0 (12.0-13.5)	C/Cg	alternating grayish brown (2.5Y5/2) fine loamy sands and dark gray (5Y4/1) silt loams; very thin (sand) and laminar (silt) bedding; loose and friable; slight effervescent; unknown lower boundary; few rootlets in silt loams.
487.7-515.1 (16.0-16.9)	C/Cg	as above except black (N/0) mucky peat bed at 512.1-513.6 cm (16.8-16.9 ft); gradual lower boundary.
518.2-527.3 (17.0-17.3)	Oe/Cg	alternating laminae of black (N/0) peaty muck and dark gray (5Y4/1) silt loam; laminar; friable; non-effervescent; unknown lower boundary; peat plant fibers yielded a conventional radiocarbon age of 8,350 ± 40 B.P. (Beta-281005).
609.6-646.2 (20.0-21.2)	Oe/Cg	same as above except bedding has irregular abrupt boundaries – photo (wood in foil).
646.2-655.3 (21.2-21.5)	O	wood log; photo of wood in foil wrap; wood yielded a conventional radiocarbon age of 10,420 ± 70 B.P. (Beta-279900)
655.3-658.4 (21.5-21.6)	C	dark grayish brown to grayish brown (2.5Y4/2-5/2) fine loamy sand; single grain; loose; non-effervescent; unknown lower boundary.
731.5-792.5 (24.0-26.0)	C	grayish brown to dark grayish brown (2.5Y5/2-4/2) medium to coarse sand; single grain; loose; slight effervescence; unknown lower boundary; fining-up sequence.
792.5-829.1 (26.0-27.2)	C	grayish brown to dark grayish brown (2.5Y5/2-4/2) pebbly coarse sand coarsening downward to coarse sandy gravel; single grain; loose; slight effervescent; unknown lower boundary; fining-up sequence; well rounded

		exotic pebbles and gravels; subangular to well rounded local pebbles and gravels (photo).
853.4-944.9 (28.0-31.0)	C	collected Optical Spectral Luminescence Sample; sample was too coarse of texture for OSL date.
End of Boring @ 944.9 (31.0)		

Core/Profile: 10GD03 (SB-15)
Location: County Road 2 Boulevard approximately 1000 feet south of Villa Maria Academy entrance
Legal description: NE NW Section 13 T112N R13W
Latitude/Longitude: 44.5108438652/-92.3240118911 (WGS84 horizontal datum)
County: Goodhue
Parent material: Wetland/alluvium
Vegetation: Canary reed grass and other marginal wetland plants
Slope: 3-5%
Elevation: 679.1 feet (207.0 meters)
Remarks: Located on alluvial fan at the Mississippi River bluff line

Depth cm(ft)	Horizon or Zone	Description
0.0-16.8 (0.0-0.6)	Ap1	very dark gray (10YR3/1) loam; weak fine granular; friable; slight effervescence; abrupt lower boundary; topsoil fill.
16.8-29.0 (0.6-1.0)	Ap2	very pale brown (10YR7/4) CO_3 aggregate; single grain; loose; strong to violent effervescence; abrupt lower boundary; old road ballast.
29.0-61.0) (1.0-2.0)	Ap3	very dark gray (10YR3/1) sandy clay loam diamicton; few very pale brown (10YR7/4) dissolved CO_3 pebbles; massive; firm; slight effervescence; abrupt lower boundary; subbase for road.
61.0-106.7) (2.0-3.5)	C(Ap?)	dark brown to dark yellowish brown (10YR3/3-3/4) pebbly loamy sand; single grain; loose; non-effervescent; unknown lower boundary; possible natural flood deposit.
121.9-143.3) (4.0-4.7)	C(Ap?)	as above except abrupt lower boundary.
143.3-169.2 (4.7-5.6)	M	manufactured horizon; asphalt road bed; abrupt lower boundary.
169.2-192.0) (5.6-6.3)	Cg	dark olive gray (5Y3/2) sandy clay loam with pebbles; massive; firm; spotty effervescence; unknown lower boundary; probably natural bed; pebbles are well rounded and exotic up to 4x3x5.5 cm.
243.8-277.4 (8.0-9.1)	Cg	same as above except non-effervescent.
365.8-368.8 (12.0-12.1)	Cg	black (5Y2.5/1) fine silt; massive; friable; non-effervescent; abrupt lower boundary; slackwater deposit with small black root (collected); root yielded a Modern Date (Beta-279901)
368.8-393.2 (12.1-12.9)	Cg	very dark gray (5Y3/1) pebbly coarse sand; single grain; loose; spotty effervescence; unknown lower boundary; mostly well rounded exotics; few well rounded local carbonates (photo).
426.7-438.9 (14.0-14.4)	Cg	as above except few cobbles that refused core – one cobble was a vuggy red basalt or rhyolite after being freshly broken.
End of Boring @ 438.9 (14.4)		

Core/Profile: 10WB01 (SB-16)
Location: Wabasha County Road 14 approximately 1500 feet southwest of Township Road T-631
Legal description: SW SW Section 23 T109N R10W
Latitude/Longitude: 44.2231962614/-91.9858198143 (WGS84 horizontal datum)
County: Wabasha
Parent material: Slackwater/alluvium deposits
Vegetation: Grass
Slope: 5-9%
Elevation: 759.8 feet (231.6 meters)
Remarks: Road ditch (photo)

Depth cm(ft)	Horizon or Zone	Description
0.0-24.4 (0.0-0.8)	Ap	dark grayish brown (10YR4/2) silt loam; common fine to medium distinct yellowish brown (10YR5/6) mottles; weak fine subangular blocky; friable; non-effervescent; clear lower boundary.
24.4-83.8 (0.8-2.8)	Bt	yellowish brown ((10YR5/6) silty clay loam; common medium distinct grayish brown (10YR5/2) mottles; very weak fine subangular blocky; firm; non-effervescent; unknown lower boundary.
121.9-139.9 (4.0-4.6)	Bt	same as above except clear lower boundary.
139.9-185.3 (4.6-6.1)	C	weak red (10R4/4) silty clay loam; many coarse prominent yellowish brown (10YR5/6) mottles; laminar to very thinly bedded; firm; non-effervescent; clear lower boundary; red beds; photo 3.
185.3-205.7 (6.1-6.8)	C	grayish brown to light grayish brown (10YR5/2-6/2) silt loam to silty clay loam; many medium distinct laminar yellowish brown (10YR5/8) mottles; faint laminar bedding; firm; slight effervescence; unknown lower boundary.
243.8-304.8 (8.0-10.0)	C	same as above except few soft pipe stems and mollusk shell fragments; weak red (10R5/4) thin bed at 280.6-283.7 (9.2-9.3 ft).
365.8-457.2 (12.0-15.0)	C	yellowish brown (10YR5/4) grading downward to brown (10YR5/3) fine silt loam; common medium and thin strong brown (7.5YR5/6) and very few dark reddish brown (5YR3/3) mottles; massive downward to laminar; friable; slight effervescence; unknown lower boundary.
487.68-579.12 (16.0-19.0)	C	same as above except entirely laminar with common thin lenses of brown (10YR5/3) fine sandy loam, which increase in frequency downwards; few MnOx thin beds.
609.6-624.8 (20.0-20.5)	C	same as above except entirely yellowish brown (10YR5/4) silt loam with common thin fine sandy loam lenses.
624.8-652.9 (20.5-21.4)	C	gray to pinkish gray (5YR6/1-6/2) silt loam; many medium thick light yellowish brown (2.5Y6/4) very fine sand lenses; laminar to thin; friable; gray to pinkish gray has slight effervescence, yellowish brown is non-effervescent; abrupt lower boundary.
652.9-680.6 (21.4-22.3)	C	light yellowish brown (2.5Y6/4) sandy loam diamicton; common fine prominent strong brown (7.5YR5/6) mottles; massive; friable; slight effervescence; unknown lower boundary; mostly to partially matrix supported, local angular weathered sedimentary bedrock; probable colluvial mass wasting deposit.
731.5-764.4 (24.0-25.1)	C	brown (7.5YR5/2) silt loam; many thin distinct strong brown (7.5YR4/6) mottles; laminar; friable; slight effervescence; angular abrupt lower boundary.
764.4-784.9 (25.1-25.8)	C	strong brown (7.5YR5/8) very fine sandy loam; common thin to laminar MnOx mottles; laminar to thin bedding; very friable; non-effervescent; abrupt lower boundary.
784.9-805.3 (25.8-26.4)	C	grayish brown (2.5Y5/2) sandy clay loam; many medium, faint light olive brown (2.5Y5/4) mottles; laminar to thin; friable; non-effervescent; unknown lower boundary.
853.4-970.2 (28.0-31.8)	C	light olive brown (2.5Y5/6) sandy clay loam with very light olive gray to

		pale olive (5Y6/2-6/3) weathered sandstone cobbles; common coarse prominent strong brown (7.5YR5/8) mottles; crude bedding; friable; non-effervescent; unknown lower boundary.
975.4-1066.8 (32.0-35.0)	CR	same as above except sandstone clasts are now boulder size.
1066.8-1072.0 (35.0-35.2)	R	refusal on probable sandstone bedrock; may be large boulder.
End of Boring @ 1072.0 (35.2)		

Core/Profile: 10WN01 (SB-17)
Location: Winona County Road 23 approximately 3500 feet south of Sherry Drive
Legal description: NW NE NE SEC. 15 T107N R8W
Latitude/Longitude: 44.0775865568/-91.764583138 (WGS84 horizontal datum)
County: Winona
Parent material: Alluvium/slackwater deposits
Vegetation: Row crops
Slope: 0-5%
Elevation: 738.8 feet (225.2 meters)
Remarks: Reddish topsoil colors. Photo 1.

Depth cm(ft)	Horizon or Zone	Description
0.0-22.9 (0.0-0.8)	Ap	very dark brown (10YR2/2) silty clay loam; common medium prominent brown (7.5YR5/4) and grayish brown (2.5Y5/2) mottles; massive; firm; non-effervescent; abrupt lower boundary.
22.9-43.3 (0.8-1.4)	Bt	grayish brown (2.5Y5/2) silty clay to silty clay loam; many medium prominent brown (7.5YR5/4) mottles; moderate medium subangular blocky; few thin distinct cutans; firm; non-effervescent; clear lower boundary; medium soft pipestems.
43.3-86.3 (1.4-2.8)	BC	same as above except no pipestems, weak to massive subangular blocky, and few fine reddish yellow (7.5YR6/8) mottles.
121.9-200. 6 (4.0-6.6)	C	brown to yellowish brown (10YR5/3-5/4) silty clay loam; few fine distinct light brownish gray (10YR6/2) and few fine distinct strong brown (7.5YR5/6) mottles; laminar to thin bedding; non-effervescent; unknown lower boundary; few thin soft pipestems and decayed roots.
243.8-266.7 (8.0-8.8)	C	same as above except abrupt lower boundary.
266.7-327.7 (8.8-10.8)	C	brown to yellowish brown (7.5YR-10YR5/4) silt loam; few fine prominent grayish brown (2.5Y5/2) and few thin faint strong brown (7.5YR5/6) mottles; common thin MnOx stains on bedding planes; thin to laminar bedding; friable; slight to strong (increasing downward) effervescence; unknown lower boundary.
365.8-477.6 (12.0-15.7)	C	yellowish brown to light yellowish brown to brownish yellow (10YR5/4-6/4-6/6) coarse silt loam; many thin to thick brown to strong brown (7.5YR5/4-4/6) and downwardly increasing frequency of faint to distinct grayish brown (10YR5/2) mottles; laminar to thinly bedded; friable; slight to strong effervescence; unknown lower boundary.
487.7-563.9 (16.0-18.5)	C	light brownish gray to light gray (10YR6/2-7/2) silt loam; many thinly bedded distinct yellowish brown (10YR5/6) mottles of loam textures; common thin to medium beds of light brownish gray to light gray (10YR6/2-7/2) clay loams interbedded with the silt loams; laminar to thinly bedded; friable to firm; slight to strong effervescence; unknown lower boundary.
609.6-723.9 (20.0-23.8)	C	same as above except brown to pinkish gray (7.5YR5/2-6/2); rounded exotic fine pebbly silty clay loam bed (matrix supported) at 622.7-625.3 cm (20.4-20.5 ft), and gray (10YR4/1) silty clay loam bed at 668.5-671.0 cm (21.9-22.0 ft).
731.5-754.4 (24.0-24.8)	C	brown to pinkish gray (7.5YR5/2-6/2) silt loam; many thinly bedded distinct yellowish brown (10YR5/6) mottles of loamy textures; common thin to medium beds of light brownish gray to light gray (10YR6/2-7/2) clay loams interbedded with the silt loams; laminar to thinly bedded; friable to firm; slight to strong effervescence; abrupt lower boundary.
754.4-817.8 (24.8-26.8)	Cg	dark gray (5Y4/1) silt loam; common thin to laminar black mottles (N/0) of peat; laminar to thin bedding; friable; slight effervescence; unknown lower boundary; very delicate and intricately webbed fiber from a single wetland plant was collected under the microscope and this fiber yielded a

		conventional radiocarbon age of 18,750 ± 70 B.P. (Beta-279902).
853.4-927.2 (28.0-30.4)	Cg	same as above except for one fine pebbly silty clay loam bed (matrix supported) at 912.5-917.5 cm; pebbles were exotic and sub- to well rounded; and no apparent peaty lenses.
EndBoring @ 927.2 (30.4)		

Appendix E

Radiocarbon Lab Data

BETA

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Fax: 305 663 0964
Beta@radiocarbon.com
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Darden Hood
President

Ronald Hatfield
Christopher Patrick
Deputy Directors

July 5, 2010

Mr. Curtis M. Hudak
Foth Infrastructure & Environment, LLC
8550 Hudson Boulevard North
Suite 105
Lake Elmo, MN 55042
USA

RE: Radiocarbon Dating Result For Sample 10GD-02 (17.0-17.3 ft)

Dear Mr. Hudak:

Enclosed is the radiocarbon dating result for one sample recently sent to us. It provided plenty of carbon for an accurate measurement and the analysis proceeded normally. As usual, the method of analysis is listed on the report sheet and calibration data is provided where applicable.

As always, no students or intern researchers who would necessarily be distracted with other obligations and priorities were used in the analysis. It was analyzed with the combined attention of our entire professional staff.

If you have specific questions about the analyses, please contact us. We are always available to answer your questions.

The cost of the analysis was charged to the American Express card provided. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood
Digital signature on file

BETA ANALYTIC INC.

DR. M.A. TAMERS and MR. D.G. HOOD

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MIAMI, FLORIDA, USA 33155
PH: 305-667-5167 FAX:305-663-0964
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REPORT OF RADIOCARBON DATING ANALYSES

Mr. Curtis M. Hudak — Report Date: 7/5/2010

Foth Infrastructure & Environment, LLC — Material Received: 6/23/2010

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 281005	8350 +/- 40 BP	-24.8 o/oo	8350 +/- 40 BP

SAMPLE : 10GD-02 (17.0-17.3 ft)
ANALYSIS : AMS-ADVANCE delivery
MATERIAL/PRETREATMENT : (plant material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 7520 to 7330 (Cal BP 9470 to 9280)

Dates are reported as RCYBP (radiocarbon years before present, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby 14C half-life (5568 years). Quoted errors represent 1 relative standard deviation statistics (68% probability) counting errors based on the combined measurements of the sample, background, and modern reference standards. Measured 13C/12C ratios (delta 13C) were calculated relative to the PDB-1 standard.

The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the delta 13C. On rare occasion where the Conventional Radiocarbon Age was calculated using an assumed delta 13C, the ratio and the Conventional Radiocarbon Age will be followed by "*". The Conventional Radiocarbon Age is not calendar calibrated. When available, the Calendar Calibrated result is calculated from the Conventional Radiocarbon Age and is listed as the "Two Sigma Calibrated Result" for each sample.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.8:lab. mult=1)

Laboratory number: **Beta-281005**

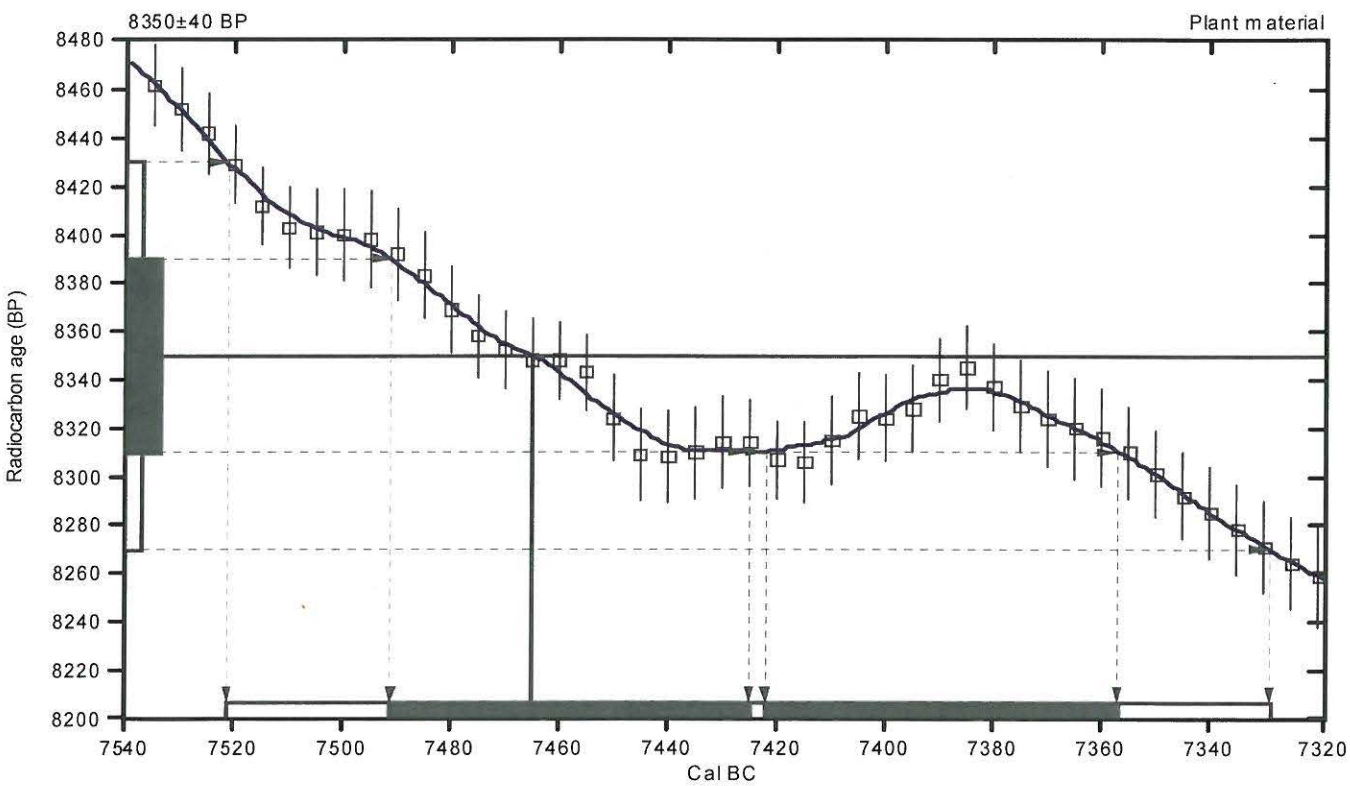
Conventional radiocarbon age: **8350±40 BP**

2 Sigma calibrated result: **Cal BC 7520 to 7330 (Cal BP 9470 to 9280)**
(95% probability)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 7460 (Cal BP 9420)

1 Sigma calibrated results: Cal BC 7490 to 7420 (Cal BP 9440 to 9380) and
(68% probability) Cal BC 7420 to 7360 (Cal BP 9370 to 9310)



References:

Database used
INTCAL04
Calibration Database
INTCAL04 Radiocarbon Age Calibration
IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

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Darden Hood
President

Ronald Hatfield
Christopher Patrick
Deputy Directors

June 21, 2010

Mr. Curtis M. Hudak
Foth Infrastructure & Environment, LLC
8550 Hudson Boulevard North
Suite 105
Lake Elmo, MN 55042
USA

RE: Radiocarbon Dating Results For Samples 10DK-01 15.5 ft, 10DK-03 4.0-4.55 ft, 10DK-03 8.4 ft, 10DK-12 29.95-30.30 ft, 10GD-02 21.2-21.5 ft, 10GD-03 12.0-12.1 ft, 10WN-01 24.75-26.83 ft

Dear Mr. Hudak:

Enclosed are the radiocarbon dating results for seven samples recently sent to us. They each provided plenty of carbon for accurate measurements and all the analyses proceeded normally. As usual, the method of analysis is listed on the report with the results and calibration data is provided where applicable.

You will notice that Beta-279901 (10GD-03 12.0-12.1 ft) is reported with the units "pMC" rather than BP. "pMC" stands for "percent modern carbon". Results are reported in the pMC format when the analyzed material had more ^{14}C than did the modern (AD 1950) reference standard. The source of this "extra" ^{14}C in the atmosphere is thermo-nuclear bomb testing which on-set in the 1950s. Its presence generally indicates the material analyzed was part of a system that was respiring carbon after the on-set of the testing (AD 1950s). On occasion, the two sigma lower limit will extend into the time region before this "bomb-carbon" onset (i.e. less than 100 pMC). In those cases, there is some probability for 18th, 19th, or 20th century antiquity.

If you have specific questions about the analyses, please contact us. We are always available to answer your questions.

The cost of the analysis was charged to the American Express card provided. A receipt is enclosed. Thank you. As always, if you have any questions or would like to discuss the results, don't hesitate to contact me.

Sincerely,

Darden Hood
Digital signature on file

BETA ANALYTIC INC.
DR. M.A. TAMERS and MR. D.G. HOOD

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REPORT OF RADIOCARBON DATING ANALYSES

Mr. Curtis M. Hudak — Report Date: 6/21/2010

Foth Infrastructure & Environment, LLC — Material Received: 5/25/2010

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279895	NA	-24.6 o/oo	> 43500 BP

SAMPLE : 10DK-01 15.5 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (organic material): acid/alkali/acid
2 SIGMA CALIBRATION : The result is outside of calibration range.
COMMENT:

(1) The 14C activity was extremely low and almost identical to the background signal. In such cases, indeterminate errors associated with the background add non-measurable uncertainty to the result. Always, the result should be considered along with other lines of evidence. The most conservative interpretation of age is infinite (i.e. greater than).

(2) A Measured Radiocarbon Age is not reported for infinite dates since corrections may imply a greater level of confidence than is appropriate.

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279897	1860 +/- 40 BP	-28.1 o/oo	1810 +/- 40 BP

SAMPLE : 10DK-03 4.0-4.55 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (peat): acid/alkali/acid
2 SIGMA CALIBRATION : Cal AD 120 to 260 (Cal BP 1830 to 1680) AND Cal AD 280 to 330 (Cal BP 1670 to 1620)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279898	18050 +/- 70 BP	-26.6 o/oo	18020 +/- 70 BP

SAMPLE : 10DK-03 8.4 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 19550 to 19180 (Cal BP 21500 to 21120)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279899	9770 +/- 50 BP	-24.9 o/oo	9770 +/- 50 BP

SAMPLE : 10DK-12 29.95-30.30 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (organic sediment): acid washes
2 SIGMA CALIBRATION : Cal BC 9300 to 9200 (Cal BP 11250 to 11150)

Dates are reported as RCYBP (radiocarbon years before present, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby 14C half-life (5568 years). Quoted errors represent 1 relative standard deviation statistics (68% probability) counting errors based on the combined measurements of the sample, background, and modern reference standards. Measured 13C/12C ratios (delta 13C) were calculated relative to the PDB-1 standard.

The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the delta 13C. On rare occasion where the Conventional Radiocarbon Age was calculated using an assumed delta 13C, the ratio and the Conventional Radiocarbon Age will be followed by "*". The Conventional Radiocarbon Age is not calendar calibrated. When available, the Calendar Calibrated result is calculated from the Conventional Radiocarbon Age and is listed as the "Two Sigma Calibrated Result" for each sample.

BETA

BETA ANALYTIC INC.

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REPORT OF RADIOCARBON DATING ANALYSES

Mr. Curtis M. Hudak

Report Date: 6/21/2010

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279900	10430 +/- 70 BP	-26.0 o/oo	10420 +/- 70 BP

SAMPLE : 10GD-02 21.2-21.5 ft
ANALYSIS : Radiometric-Standard delivery
MATERIAL/PRETREATMENT : (wood): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 10700 to 10110 (Cal BP 12650 to 12060)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279901	150.4 +/- 0.6 pMC	-28.2 o/oo	151.4 +/- 0.6 pMC

SAMPLE : 10GD-03 12.0-12.1 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (wood): acid/alkali/acid
COMMENT: The reported result indicates an age of post 0 BP and has been reported as a % of the modern reference standard, indicating the material was living within the last 50 years ("pMC" = percent modern carbon).

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 279902	18760 +/- 70 BP	-25.4 o/oo	18750 +/- 70 BP

SAMPLE : 10WN-01 24.75-26.83 ft
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (plant material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 20460 to 20260 (Cal BP 22410 to 22210)

Dates are reported as RCYBP (radiocarbon years before present, "present" = AD 1950). By international convention, the modern reference standard was 95% the 14C activity of the National Institute of Standards and Technology (NIST) Oxalic Acid (SRM 4990C) and calculated using the Libby 14C half-life (5568 years). Quoted errors represent 1 relative standard deviation statistics (68% probability) counting errors based on the combined measurements of the sample, background, and modern reference standards. Measured 13C/12C ratios (delta 13C) were calculated relative to the PDB-1 standard.

The Conventional Radiocarbon Age represents the Measured Radiocarbon Age corrected for isotopic fractionation, calculated using the delta 13C. On rare occasion where the Conventional Radiocarbon Age was calculated using an assumed delta 13C, the ratio and the Conventional Radiocarbon Age will be followed by "*". The Conventional Radiocarbon Age is not calendar calibrated. When available, the Calendar Calibrated result is calculated from the Conventional Radiocarbon Age and is listed as the "Two Sigma Calibrated Result" for each sample.

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-28.1:lab. mult=1)

Laboratory number: **Beta-279897**

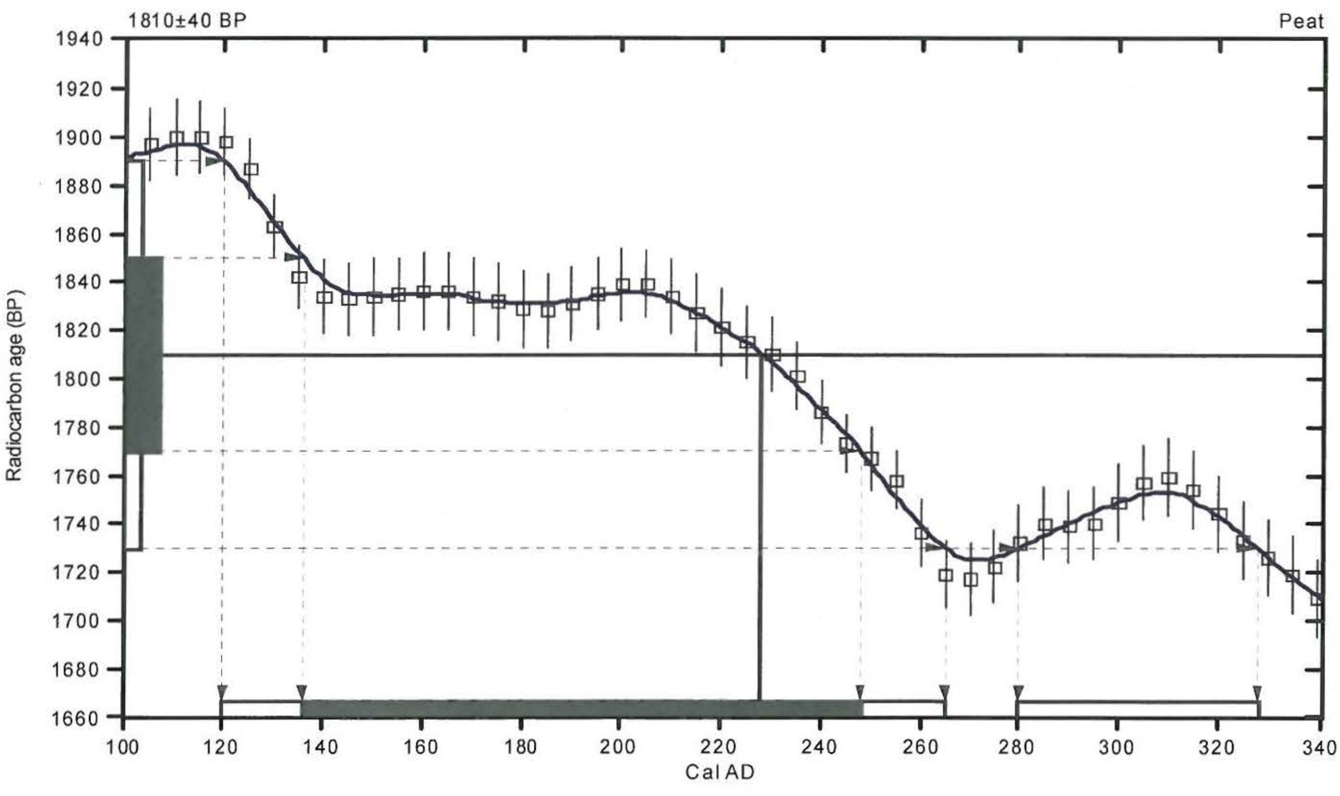
Conventional radiocarbon age: **1810±40 BP**

2 Sigma calibrated results: (95% probability) **Cal AD 120 to 260 (Cal BP 1830 to 1680) and Cal AD 280 to 330 (Cal BP 1670 to 1620)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal AD 230 (Cal BP 1720)

1 Sigma calibrated result: (68% probability) Cal AD 140 to 250 (Cal BP 1810 to 1700)



References:

Database used
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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26.6:lab. mult=1)

Laboratory number: Beta-279898

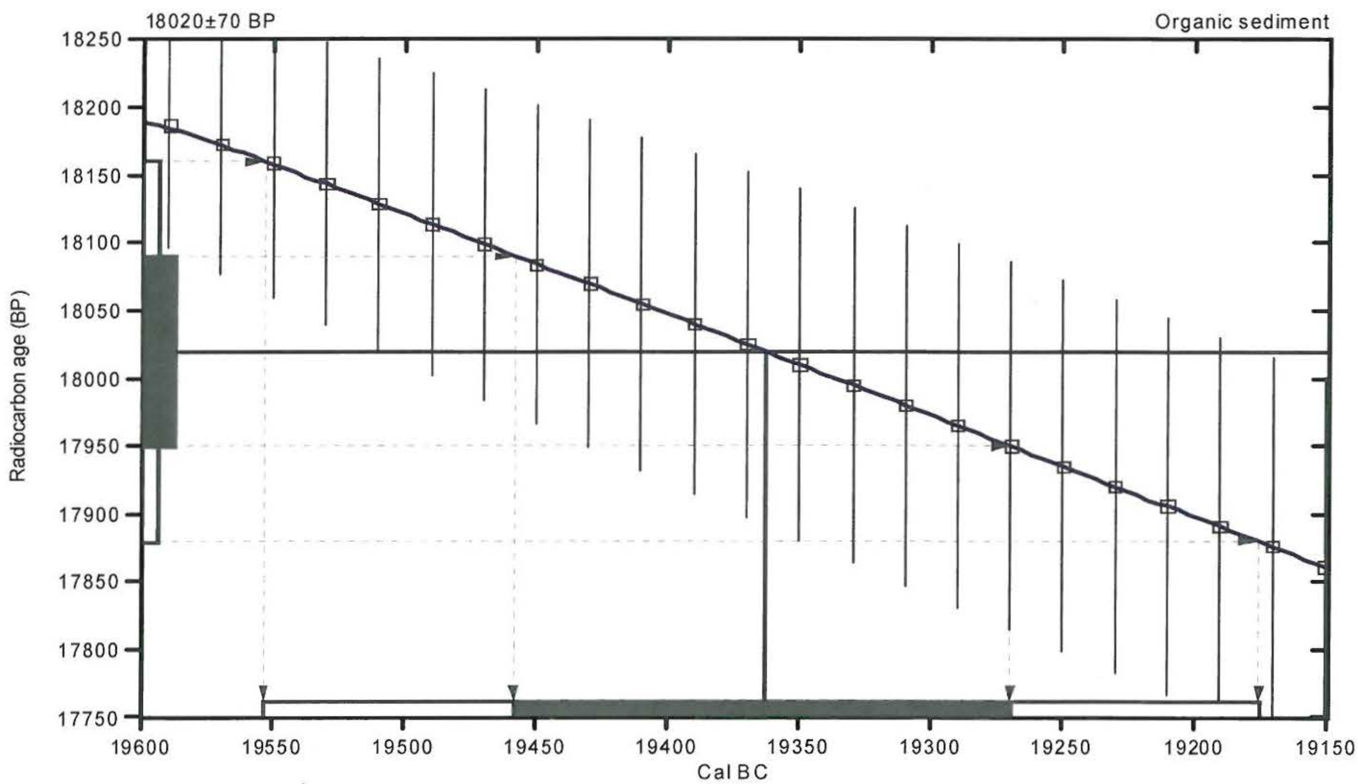
Conventional radiocarbon age: 18020±70 BP

2 Sigma calibrated result: Cal BC 19550 to 19180 (Cal BP 21500 to 21120)
(95% probability)

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 19360 (Cal BP 21310)

1 Sigma calibrated result: Cal BC 19460 to 19270 (Cal BP 21410 to 21220)
(68% probability)



References:

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.9:lab. mult=1)

Laboratory number: **Beta-279899**

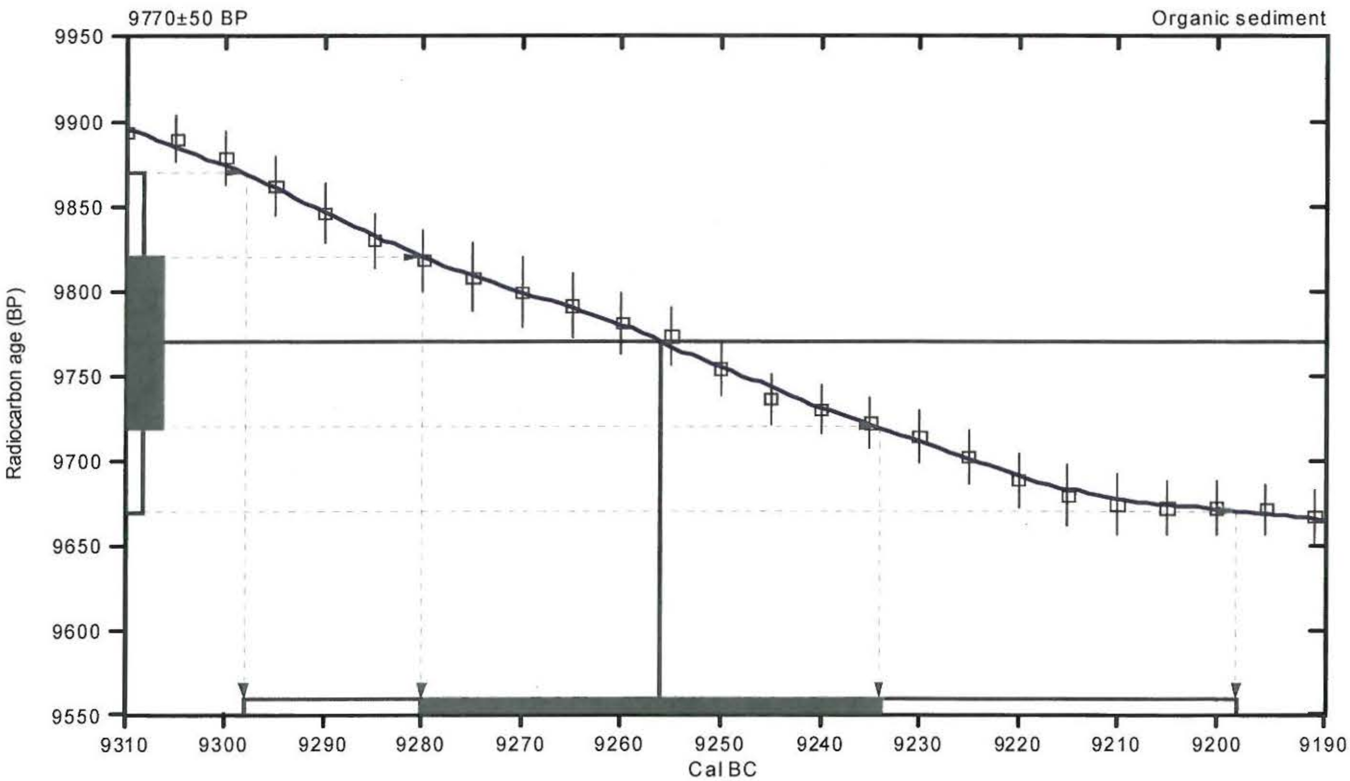
Conventional radiocarbon age: **9770±50 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 9300 to 9200 (Cal BP 11250 to 11150)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 9260 (Cal BP 11210)

1 Sigma calibrated result: (68% probability) Cal BC 9280 to 9230 (Cal BP 11230 to 11180)



References:

Database used

INTCAL04

Calibration Database

INTCAL04 Radiocarbon Age Calibration

IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).

Mathematics

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-26:lab. mult=1)

Laboratory number: **Beta-279900**

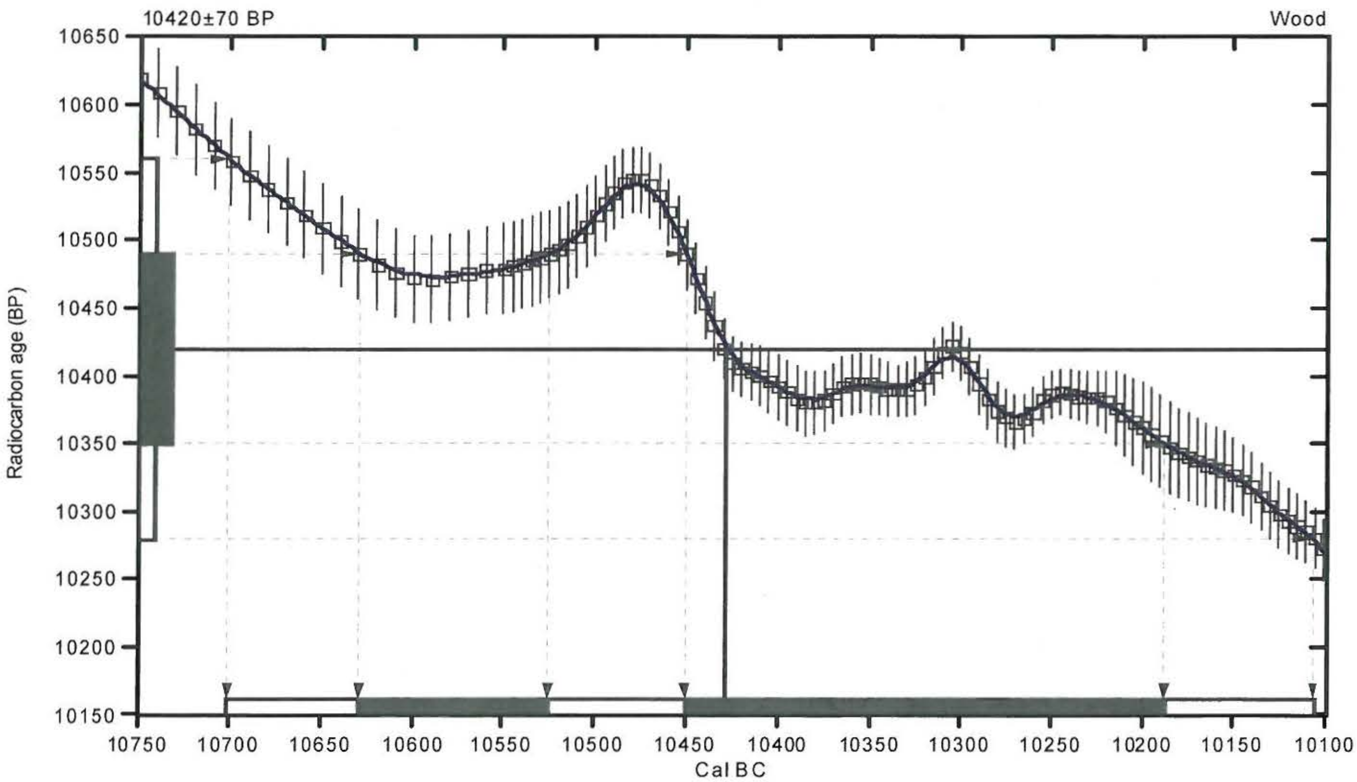
Conventional radiocarbon age: **10420±70 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 10700 to 10110 (Cal BP 12650 to 12060)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 10430 (Cal BP 12380)

1 Sigma calibrated results: (68% probability) Cal BC 10630 to 10520 (Cal BP 12580 to 12480) and Cal BC 10450 to 10190 (Cal BP 12400 to 12140)



References:

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-25.4:lab. mult=1)

Laboratory number: **Beta-279902**

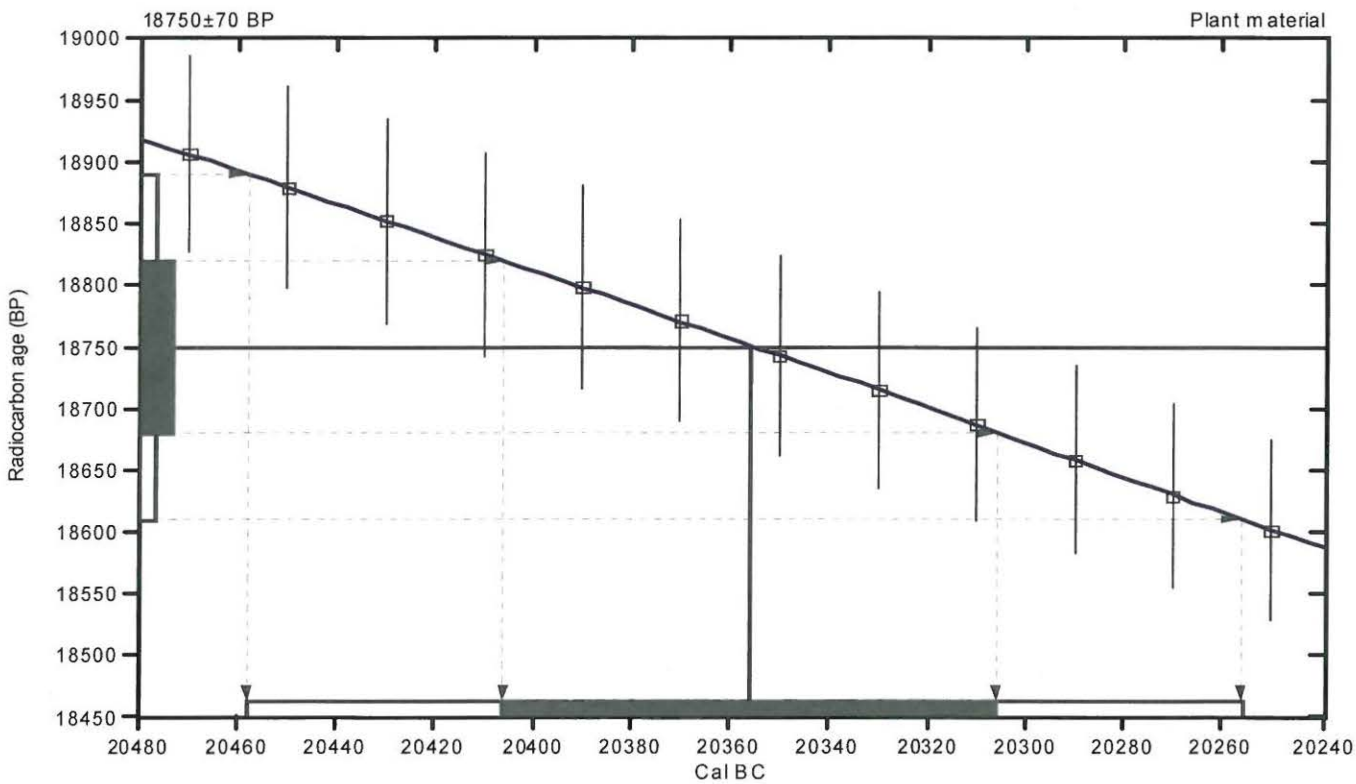
Conventional radiocarbon age: **18750±70 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 20460 to 20260 (Cal BP 22410 to 22210)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 20360 (Cal BP 22310)

1 Sigma calibrated result: (68% probability) Cal BC 20410 to 20310 (Cal BP 22360 to 22260)



References:

Database used

INTCAL04

Calibration Database

INTCAL04 Radiocarbon Age Calibration

IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

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