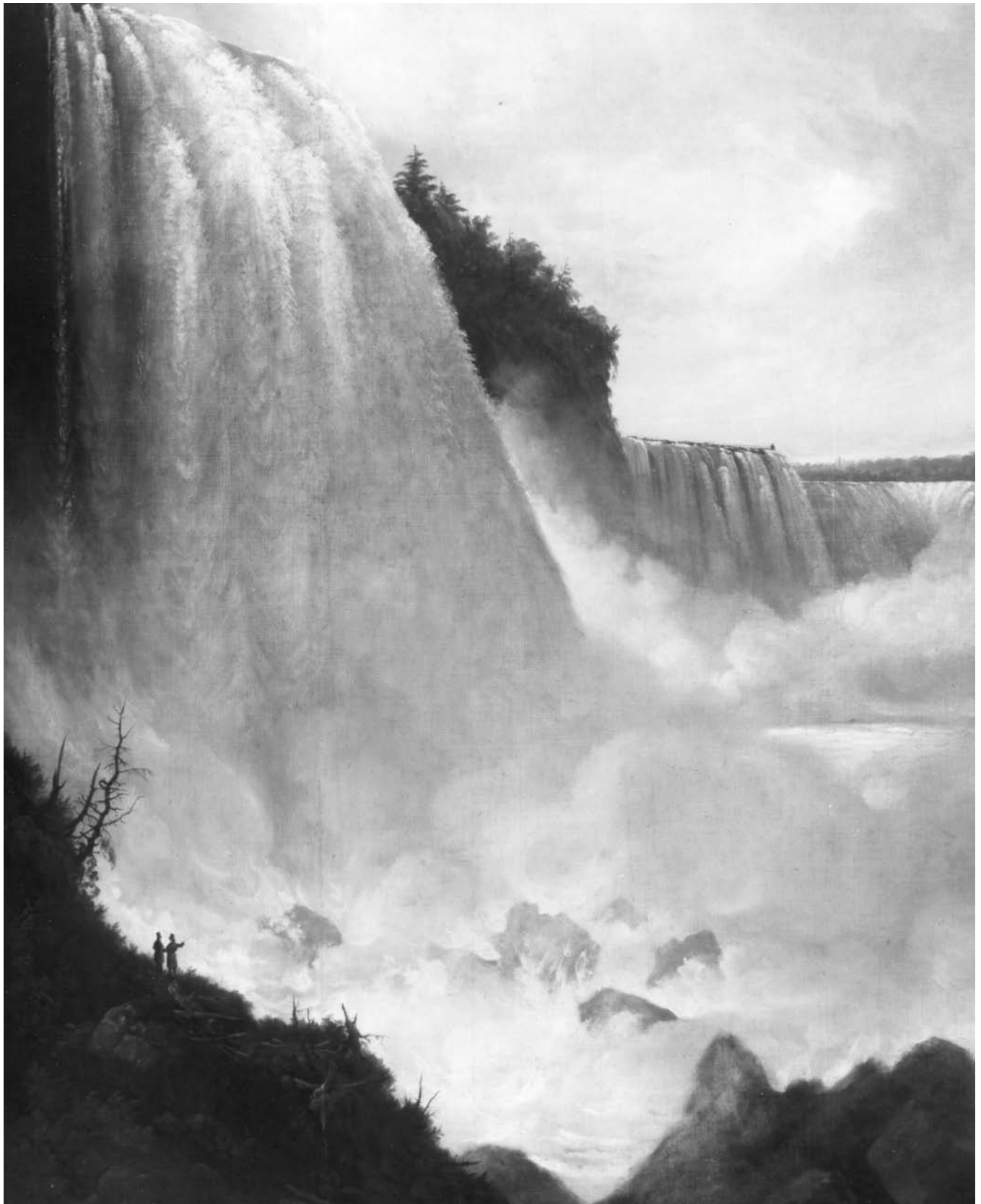


# *River of History*

**A Historic Resources Study of the Mississippi  
National River and Recreation Area**



*FIGURE 1. What the Glacial River Warren Falls might have looked like in St. Paul 12,000 years ago. Gustav Grunewal, Horseshoe Falls from below High Bank. Fine Arts Museums of San Francisco. Gift of John Davis Hatch, V, in memory of John Davis Hatch, A.I.A., architect of San Francisco, 1996.52.2.*

## Chapter 1

# The Geology of the MNRRA Corridor

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This chapter is about foundations. As subsequent chapters show, landforms created thousands to millions of years ago shaped the corridor's development. Native American villages, early American settlements, milling sites, locks and dams, railroads, roads and modern urban expansion overlay or responded to ancient geologic processes. A cursory glance at the present-day Mississippi River valley reveals that the geologic processes operating during the valley's formation were much different from those of today. This chapter summarizes the current knowledge regarding the physical history of the Mississippi River valley. It includes a brief introduction to some of the early studies of the valley's geology, an overview of the valley's geologic configuration, and a summary of geologic events responsible for the valley's appearance today.

The Mississippi River winds more than 2,300 miles across the heart of the nation on its course to the Gulf of Mexico. In Minnesota, the river flows over 660 miles from its source at Lake Itasca through bogs and spruce forests in the glaciated northern region, across fertile agricultural fields in the central portion of the state, then southeastward through scenic bluff country. Along this course the river's character varies dramatically, due to the geologic events.

The Mississippi River, within the MNRRA corridor (*Figure 2*), cuts through a sequence of sedimentary rocks,

revealing a geologic history spanning over 500 million years. Spectacular bedrock bluffs are common along the river between St. Anthony Falls and Hastings. The Crow River, which marks the corridor's northern boundary, occupies an ancient glacial river channel that drained into the Mississippi. Between Dayton and Minneapolis, the river has developed on thick layers of sediment deposited during the last glacial era. Glacial sediment borders the river south of Dayton and large deposits of sand and gravel form flat-lying terraces along both sides of the river south to the confluence of the Minnesota River. Below Minneapolis, the Mississippi is cut into flat-lying, 570- to 450-million-year-old Paleozoic sedimentary rocks. Throughout the stretch from Dayton to the Minnesota River, the valley is relatively narrow and floodplain development limited.

Near Fort Snelling, the Minnesota and Mississippi Rivers join, and consequently the Mississippi valley becomes much wider. Glacial River Warren, predecessor to the Minnesota River, carved out the river's wide valley, as it carried the meltwater pouring from glacial Lake Agassiz, between 11,800 and 9,200 years before the present (B.P.). Since that time, sand, silt, and clay have been filling the valley, forming a complex mosaic of landforms across the floodplain.

Downstream from the confluence, the Mississippi heads northeast toward downtown St. Paul, bordered on

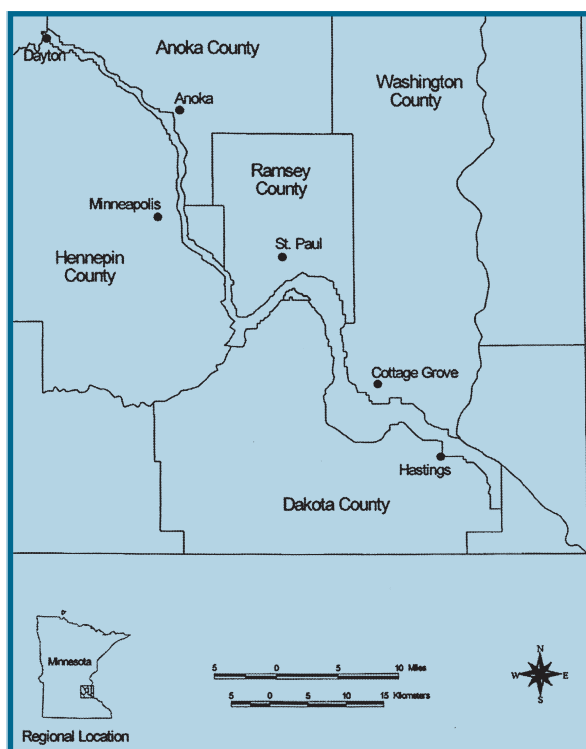


FIGURE 2. The Mississippi National River and Recreation Area located in the Twin Cities metropolitan area.

both sides by glacial terraces lying more than 100 feet above the floodplain. In this reach, glaciers did not erode the bedrock subsurface as severely. Therefore, glacial sediments are thin and terraces developed over the bedrock surface, unlike the braided outwash types occurring upstream. Going south, however, the glacial deposits form a belt of hummocky topography containing numerous depressions and lakes, typical of a recently glaciated landscape.

Just past downtown St. Paul, the Mississippi makes a wide arc and turns southward. At this point the river enters its preglacial valley, where spectacular bluffs expose the ancient bedrock. As the river winds southward toward Cottage Grove, the valley widens dramatically, due to erosion that occurred before the last glaciation. During the last glacial maximum (the farthest the glaciers advanced), this part of the river valley filled with sand and gravel deposits forming a broad level surface at an elevation of

about 120 feet above the modern floodplain.

Today the Vermillion River joins the Mississippi at Hastings, forming a large alluvial fan and diverting the channel of the Mississippi to the northeast. Alluvium accumulating on the floodplain near the confluence has formed a delta in the Mississippi that has been migrating downstream for the last 9,500 years. Backwater lakes and sloughs, meandering secondary channels, and small terrace remnants characterize the floodplain at the southern end of the MNRRA corridor. This area was once part of Lake Pepin, the large river lake downstream, and at one time may have extended up to St. Paul.

### Early Investigations

The first studies into the geologic history of Minnesota began in the 1870s under Newton H. Winchell, at the newly formed Minnesota Geological and Natural History Survey. Winchell, with the aid of Warren Upham, began mapping and describing the surface geology in central Minnesota. Most of the surface features in the area developed in response to continental glaciation during the last two million years (Quaternary Period), and their form provided clues to the processes that helped shape them. However, because of the scarcity of subsurface information regarding glacial stratigraphy and lack of adequate base maps covering the area, a complete understanding of the complex glacial history was never fully realized.

Although the details of Minnesota's geologic history were not fully known, perhaps some of the most important investigations into the history of geologic development of the Mississippi River were completed at this time. Winchell was the first to address the retreat of St. Anthony Falls from its former position at the confluence of the Mississippi and Minnesota Rivers upstream to its present location.<sup>1</sup> Using the final ice retreat from Minnesota as a basis he estimated that it took approximately 7,800 years for the waterfall to retreat, a figure that has proven remarkably close to current estimates. Upham conducted a detailed study of glacial Lake Agassiz, whose outlet stream, glacial River Warren,

had a profound effect on the Mississippi River valley's shape and configuration. His work led to the publication of a huge monograph detailing Lake Agassiz's development and drainage.<sup>2</sup>

The Minnesota Geological and Natural History Survey officially ended in the early 1900s following the retirement of Winchell and Upham. Shortly thereafter, Frank Leverett, with the aid of Frederick Sardeson, began studying the glacial history of Minnesota. Leverett and Sardeson used much of Upham's earlier work in their reevaluation of Minnesota's surface geology.<sup>3</sup> Leverett first recognized that multiple glacial advances formed the region's glacial deposits, and each subsequent advance created numerous deposits, containing distinct landforms.<sup>4</sup> The work completed during this time period was a major step forward in recognizing the complexity of the Upper Midwest's glacial history.

In addition to his work in glacial geology, Sardeson mapped and described fossils contained in the bedrock outcropping along the Mississippi River valley in southeastern Minnesota.<sup>5</sup> Sardeson also reevaluated Winchell's original estimate of retreat for St. Anthony Falls by considering the geometry and thickness of the limestone cap rock.<sup>6</sup> His calculation of 8,000 years is even closer than Winchell's to the current estimate of 10,000 years, which is based on radiocarbon dating.<sup>7</sup>

W. S. Cooper evaluated the sequence of glaciation in central Minnesota and its relation to the formation of the Mississippi River during Late Wisconsin and postglacial time.<sup>8</sup> His work detailed the origin of the Anoka Sand Plain in east central Minnesota, which formed when an advancing ice lobe diverted the Mississippi River's flow southward. A portion of the MNRRRA corridor, between Dayton and Fridley, occupies the sand plain.

From the early 1950s to the 1980s, many studies of Minnesota's glacial geologic history were conducted. Herb Wright, Jr., his colleagues, and students at the University of Minnesota completed most of them. Each study shed new light on the complexities of the glacial sequence in Minnesota and how the glacial sequence relates to develop-

ment of the Mississippi River valley.

More recently, the Army Corps of Engineers, St. Paul District has sponsored geomorphological investigations along various portions of the Mississippi River valley in conjunction with cultural resource investigations. The studies have focused on detailed mapping of surficial landforms within the floodplain environment in an effort to predict the location of buried archaeological sites. On the basis of information from these studies, it has become apparent that the Mississippi River floodplain is a dynamic environment with an ever-changing set of resources. Archaeological site distribution is a function of resource availability during the time of occupation, and geomorphic processes operating on the floodplain influence the potential for site preservation.

## General Geology

**Bedrock Geology** • Southeastern Minnesota, wherein the MNRRRA corridor lies, is composed of gently dipping sedimentary rocks that form a plateau. The Mississippi River and its tributaries have eroded this plateau extensively. Because glacial deposits have buried the bedrock, few outcrops appear along the Mississippi River above St. Anthony Falls. However, deep incision by the river below the falls has exposed the bedrock in the valley walls. The rock formations were deposited during the Cambrian and Ordovician periods (570-438 million years B.P.), when shallow seas covered southeastern Minnesota and the surrounding region. Sand accumulated along the shoreline in beaches and bars, where wave action constantly reworked it. Silt and clay formed in mud flats or settled out of relatively quiet water offshore. Calcium carbonate accumulated from the remains of biologic organisms in coral reefs and as large layers on the sea floor. The sediments eventually became compacted and cemented to form sandstone, shale, limestone, and dolomite.

The high bluffs along the river, locally averaging from 100 to 400 feet in relief, have resisted weathering and erosion. Limestone and dolomite units are strong and usually

form steep cliffs adjacent to tributary stream valleys. Shale and poorly cemented sandstone are easily eroded, forming more gentle slopes along the valley sides. Glacial processes removed much of the bedrock in the Twin Cities area. Ice followed topographic low area in the bedrock, carving out valleys during advance across the area. Stream erosion and deposition also played a major role. Glacial meltwater, flowing from the retreating ice masses, cut the valleys wider and deeper. After the glacial meltwater slowed and disappeared, the valleys gradually began filling with sediment derived from the erosion of upland surfaces.

Bedrock has been an important factor in determining the valley width, the location of glacial terraces, and the course of the Mississippi River. Valley width is controlled largely by the sedimentary properties of the bedrock. Where the river intersects more resistant carbonate units, the valley is narrow. Where poorly cemented sandstone units occur, stream flow has more effectively eroded the valley, resulting in a much greater width. Consequently, late glacial outwash terraces generally occur on top of carbonate units and occupy areas where erosion cut away the sandstone. Also, floodplain development is more extensive in areas that have greater valley width.

Each bedrock unit has a distinct set of physical characteristics setting it apart from adjacent units. From oldest to youngest, the bedrock units are: the Jordan Sandstone, Prairie du Chien Group, St. Peter Sandstone, Glenwood Shale, Platteville Limestone, Decorah Shale, and Galena Group (*Figure 3*). A brief description of the major bedrock formations outcropping in the MNRRA corridor is presented below. The Jordan Sandstone (515-505 million years B.P.) is the oldest bedrock unit outcropping within the park boundaries. Exposures are few, however, and occur only along Spring Lake near Nininger Township in the southern portion of the MNRRA corridor. The unit is a generally white, massive to well-bedded, commonly cross-bedded sandstone. Total thickness of the Jordan Sandstone is unknown, but it may be as much as 80 to 90 feet in the area around Cottage Grove.<sup>10</sup>

Overlying the Jordan Sandstone is the Ordovician Prairie du Chien Group (505-458 million years B.P.), which appears along the Mississippi River channel near South St. Paul, and in the bluffs at Hastings, forming an extensive flat-lying plateau across the upland areas. The Prairie du Chien is divided into two formations on the basis of variations in sedimentary properties. At the base of the group, the Oneota Dolomite is a light gray to buff tan, medium-grained, thinly-layered to massive dolomite. Lying above the Oneota is the Shakopee Formation, which consists of two members. The New Richmond member is a light gray, fine-grained dolomitic to glauconitic sandstone, and the Willow River member is a bluish gray dolomite similar in nature to the Oneota dolomite. Total thickness of the group ranges from 100 to 300 feet throughout the MNRRA corridor.<sup>11</sup>

One of the most extensively exposed bedrock units in the upper Mississippi River valley is the St. Peter Sandstone (458-455 million years B.P.). Exposures of this rock type are common in bluffs throughout the northern half of the MNRRA corridor. The St. Peter Sandstone consists of white to yellow, medium-grained, friable quartz sand. Because of its poorly cemented nature, the sandstone is easily eroded. On the basis of information obtained from wells in the area, total thickness of the St. Peter is approximately 150 feet.

The thinnest bedrock unit outcropping in the bluffs of the Mississippi River is a greenish gray, thinly bedded, sandy shale called the Glenwood Formation (455 million years B.P.). On average, the Glenwood ranges from 3 to 5 feet in thickness, and in some places is entirely absent. The Glenwood Shale, when present, is easily identified as a small seam of highly weathered bedrock between the underlying St. Peter Sandstone and overlying Platteville Limestone.

Possibly the most recognized bedrock formation, and one that forms relatively flat-topped benches and mesas along the Mississippi River, is the Platteville Limestone (455-454 million years B.P.). In general, the Platteville is a light gray to buff tan, thinly bedded, dolomitic limestone. Because of its highly resistant nature, the limestone serves as a caprock that

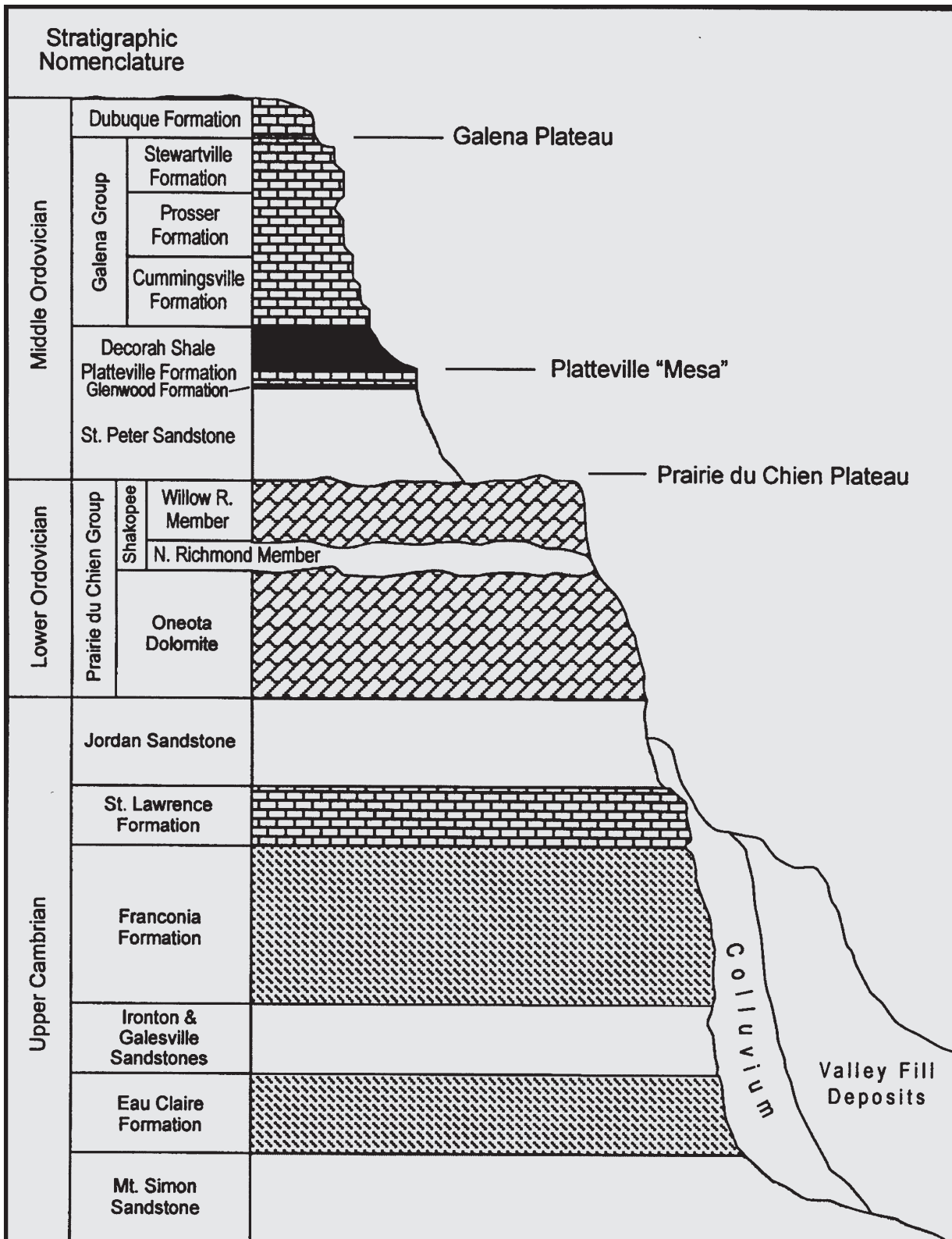


FIGURE 3. Generalized bedrock stratigraphy of the upper Mississippi River valley in southeastern Minnesota. Redrawn from Hobbs.<sup>9</sup>

is partially responsible for controlling the rate of retreat and location of waterfalls within the MNRRA corridor.

Lying above the Platteville is the Decorah Shale (454 million years B.P.), a greenish gray, calcareous shale containing thin limestone interbeds. The lateral extent of this bedrock unit across the area is limited, but it does outcrop in bluffs along the Mississippi River in St. Paul above Pickerel Lake.

The uppermost bedrock unit exposed in the MNRRA corridor is the Galena Group (454-450 million years B.P.), consisting of three members: Cummingsville Formation; Prosser Formation, and Stewartville Formation. Only the lower part of the Cummingsville is exposed within the MNRRA corridor (in southeastern Minnesota the entire Galena Group forms an extensive plateau across the uplands).

**Surficial Geology** • Surficial geologic deposits occurring within the MNRRA corridor can be separated into two general categories on the basis of their relation to the geologic history of the area. The first group, nonglacial deposits, consists of sediments that are accumulating in upland areas and along the river floodplain in response to the present geomorphic agents operating on the landscape. The second group, deposits related to glaciation, consists of sediments that were deposited during the advance and retreat of glaciers across Minnesota.

Nonglacial surficial deposits consist of three main types: organic sediments; river alluvium, and colluvium. Each deposit has a distinct environment of deposition, spatial location, and morphological expression on the landscape.

Organic deposits consist of plant material and fine-grained sediment in sloughs, lakes, and poorly drained depressions occupying the floodplain, or on upland surfaces. Plant litter continually collects at the surface, trapping silt and clay brought in by wind or fluvial activity. Soils formed from organic deposits are dark colored, water saturated, and have a mucky consistency.

Alluvium is the accumulation of sand, silt, and clay deposited by streams on riverbeds, floodplains, and alluvial

fans. The deposits often exhibit complex sedimentary properties and display a highly variable internal stratification. Individual landforms created by stream processes include point bars, cutbanks, natural levees, terraces, and numerous backwater features.

Colluvium is the unsorted mixture of weathered bedrock in a matrix of sand, silt, and clay flanking the hill slopes and cutbanks along the river valley. Colluvial deposits generally consist of two units: an upslope unit consisting of small boulders in a matrix of sediment eroded from upland areas, and a downslope unit containing large masses of bedrock slumped off the valley wall in a matrix of fine-grained sediment.

The second group of surficial deposits, those related to glaciation, consists of outwash and till deposited during the Great Ice Age. Glacial till is the unsorted mixture of pebbles, cobbles, and boulders in a matrix of sediment deposited directly from glacial ice. The compositions of rock types found in the till provide clues about the source of the deposits. Outwash typically consists of sand and gravel laid down by glacial meltwater streams flowing across the surface. Many outwash deposits consist of broad terraces that were once large braided streams draining the front of an ice sheet.

The complexity of the surficial landscape within the MNRRA corridor reflects the geologic processes operating on the surface throughout time. Many of the surficial geologic features formed in response to continental glaciation, which had a direct impact on the development of natural resources that are part of the present-day landscape.

## Glacial History of the Mississippi River

The upper Mississippi River valley has experienced a complex series of geological events since the beginning of the Quaternary Period. The Quaternary Period is divided into two formal geologic periods: the Pleistocene and Holocene Epochs. The Pleistocene, known as the Great Ice Age, spans from two million years to 10,000 years B.P. Four major ice advances are known to have taken place during the Great Ice



Age, and each has been given a name based on the geographic location of characteristic glacial deposits associated with the advance. For simplicity, the following discussion ignores the first three named glacial advances and uses the term pre-Wisconsin for glacial geologic events occurring prior to 35,000 years B.P. The Wisconsin Glaciation, spanning from about 35,000 to 10,000 years B.P., dramatically altered the landscape of Minnesota. The Holocene, or Recent Epoch, represents the last 10,000 years of geologic time.

Most of the present-day landforms developed during the multiple glacial episodes that occurred during the Wisconsin Glaciation. In Minnesota the sequence of glaciation had a direct impact on the development of the MNRRA corridor. Therefore, an overview of the glacial history of Minnesota is necessary to provide a context for discussing geologic development of the river in the MNRRA corridor.

**Pre-Wisconsin Glacial History** • In Minnesota, early glacial events within the valley have largely been obscured by late-glacial and post-glacial events. However, exposures of pre-Wisconsin drift occur at the surface in Washington and Dakota Counties.<sup>12</sup> Near the Mississippi River valley the upland landscape consists of gently rolling hills topped by a thin veneer of glacial drift or weathered bedrock residuum. A system of well-integrated stream networks, forming a dendritic (branch-like) pattern across the region, drains the uplands. Erosion along stream valleys has exposed a considerable amount of bedrock.

It is uncertain when the upper Mississippi River valley initially formed. However, on the basis of present geologic evidence, deep cutting must have occurred during the early Pleistocene.<sup>13</sup> The presence of glacial till in southeastern Minnesota, deposited during a pre-Wisconsin glacial advance, supports the theory of an early Pleistocene beginning.<sup>14</sup> The course of the upper Mississippi River along the margin of the Driftless Area of southeastern Minnesota is believed to have been established during pre-Wisconsin time when a glacial advance from the west displaced the river eastward from central Iowa to its present position.

Researchers investigating stream valleys of the Driftless Area in southwestern Wisconsin suggest deep valley incision by streams also occurred during the early Pleistocene.<sup>15</sup>

**Wisconsin Glaciation (35,000-10,000 B.P.)** • The early Pleistocene history of the Mississippi River above St. Paul has been obscured by late Wisconsin glacial events. The course of the river north of St. Paul changed repeatedly during the Pleistocene.<sup>16</sup> Presumably each major glacial phase was followed by the establishment of a new course for the river, most of which joined the present course south of St. Paul. Previously formed bedrock valleys were subsequently filled with glacial sediment derived from the Superior Lobe and Grantsburg Sublobe. The numerous lakes dotting the landscape within the Twin Cities area resulted from meltout of glacial ice blocks buried in the bedrock valleys (Figure 4).

During the late Wisconsin maximum, the Superior Lobe advanced down the axis of the Lake Superior basin southeastward to its terminal position near Minneapolis and St. Paul, while the Wadena and Rainy Lobes and Brainerd Sublobe advanced across north-central Minnesota (Figure 5a). This advance, known as the St. Croix phase of the Superior Lobe, culminated approximately 15,500 years B.P.<sup>17</sup> Little is known about the nature of the advance; however, a detailed record of ice recession has been documented.<sup>18</sup> The prominent St. Croix Moraine, a massive accumulation of glacial sediment extending from the Twin Cities northwestward to Little Falls, marks the terminus of the lobe. It is unclear where the position of the Mississippi River was at this time. The Mississippi River presently occupies a prominent gap eroded through the St. Croix Moraine. Most likely the river maintained its current position below St. Paul by continued flow underneath the advancing ice margin. Glacial outwash graded to terrace deposits along the Mississippi River in southern Washington County lends support to this hypothesis.

The St. Croix Moraine forms a northeastward trending, rugged belt of landforms containing numerous hills and

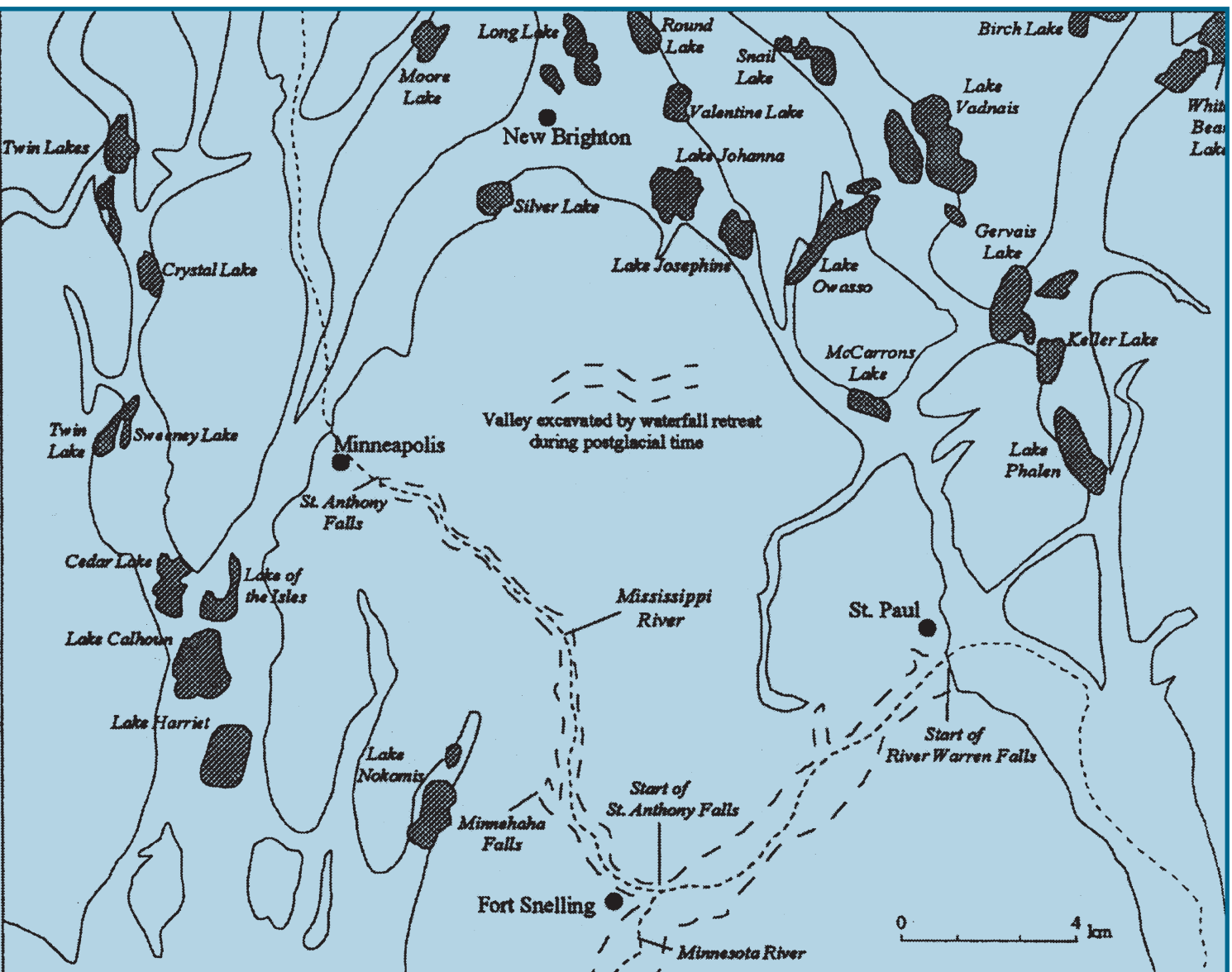


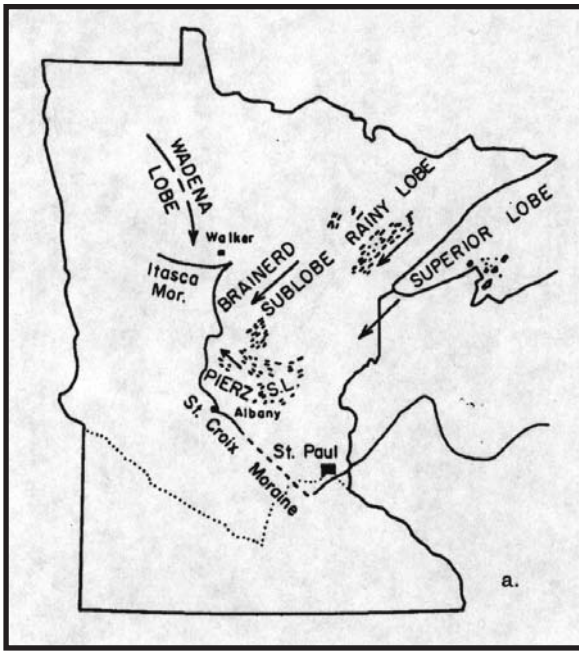
FIGURE 4. Map of preglacial bedrock valleys (solid lines) in the Twin Cities area, showing the location of present-day lakes developed by meltout of buried glacial ice. Discharge of glacial meltwater and waterfall retreat are responsible for development of present valleys (dashed lines).

associated depressions. Glacial sediment deposited during this advance consists of reddish-brown sandy till, outwash sand and gravel, and ice-contact sands and gravel.

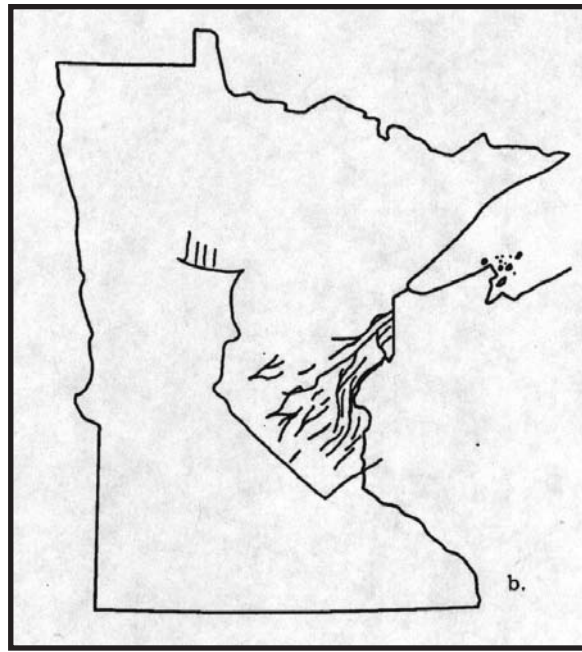
As the Superior Lobe retreated from the area, the Mississippi and St. Croix Rivers acted as the major course

for the glacial meltwater. Outwash deposits filled both valleys between an elevation of 870 and 920 feet. Meltwater streams subsequently excavated the outwash deposits during a later glacial advance.

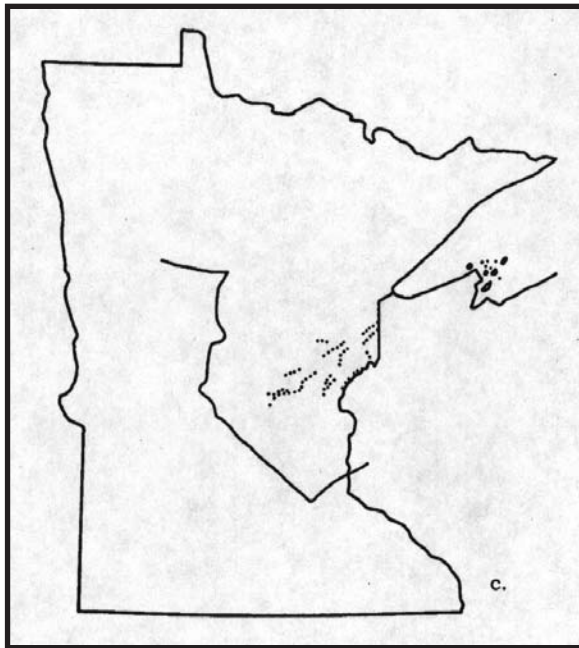
Numerous readvances, possibly surges, accompanied the retreat of the Superior Lobe from the St. Croix Moraine.<sup>19</sup> Numerous features associated with the retreating ice, including moraines and associated meltwater channels, developed behind the moraine (Figure 5b). The Mississippi River, in the central portion of the state, flowed



a) the St. Croix phase



b) development of tunnel valleys



c) deposition of eskers in tunnel valleys



d) the Automba phase

FIGURE 5. Phases of glaciation in Minnesota. Taken from Wright.<sup>16</sup>

along the western margin of the St. Croix Moraine, being fed by tunnel valleys (discrete meltwater channels) developed underneath the retreating ice lobe. Retreat of ice farther into the Lake Superior basin resulted in deposition of long, sinuous ridges of sand and gravel (eskers) within the tunnel valleys (*Figure 5c*).

The next major advance of the Superior Lobe, the Automba phase, is marked by advance of the Superior Lobe into the Mille Lacs region of east central Minnesota (*Figure 5d*). The extent of this advance is marked by the Mille Lacs Moraine, which bounds the western edge of Mille Lacs Lake in southeastern Crow Wing County, extending to the northeast as the Wright and Cromwell Moraines and then as the Highland Moraine along the north shore of Lake Superior. The Automba phase is correlated with the Tiger Cat advance in Wisconsin.<sup>20</sup> During the Tiger Cat advance, meltwater from the Superior Lobe discharged through the St. Croix River into the Mississippi River valley.

While the Superior Lobe stood at the Mille Lacs Moraine, meltwater ponded along the northwestern margin of the ice lobe, resulting in the formation of glacial lakes Aitkin I and Upham I, which presumably drained along the western end of the ice margin. The advance of the St. Louis Sublobe across the area erased any shoreline features that developed along these lakes. However, evidence for these lakes is preserved in a thin, red and gray, stone-poor till deposited by the St. Louis Sublobe after overriding the lake plain. Any evidence for the location of the Mississippi River channel in the area was destroyed by subsequent ice movements; however, it is most likely that meltwater was still channeled along the outer margin of the St. Croix Moraine down to the Mississippi valley below St. Paul.

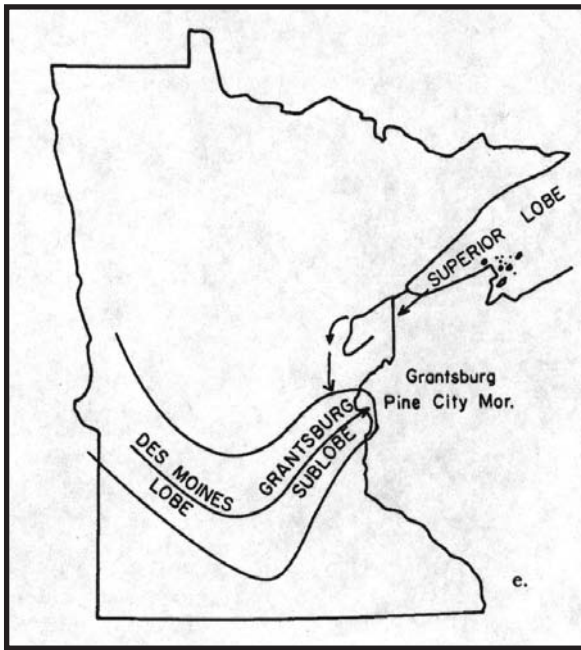
The Superior Lobe retreated from the Automba ice margin into the Superior lowland, initiating the first stage of glacial lake formation in the Superior basin. Glacial lake sediments were deposited in a large body of open water, which formed between the retreating Superior Lobe and higher topography to the southwest. Fine-grained silt and clay settled out of the melting ice mass, forming a continu-

ous blanket of sediment on the lake floor. The next advance of the Superior Lobe overrode the lakebed during the Split Rock phase, depositing a thin layer of reddish clay across previously formed deposits. The Split Rock-Pine City phase marks the readvance of the Superior Lobe to the Cloquet Moraine and the overriding of the central portion of the St. Croix Moraine by the Des Moines Lobe (*Figure 5e, 5f*).

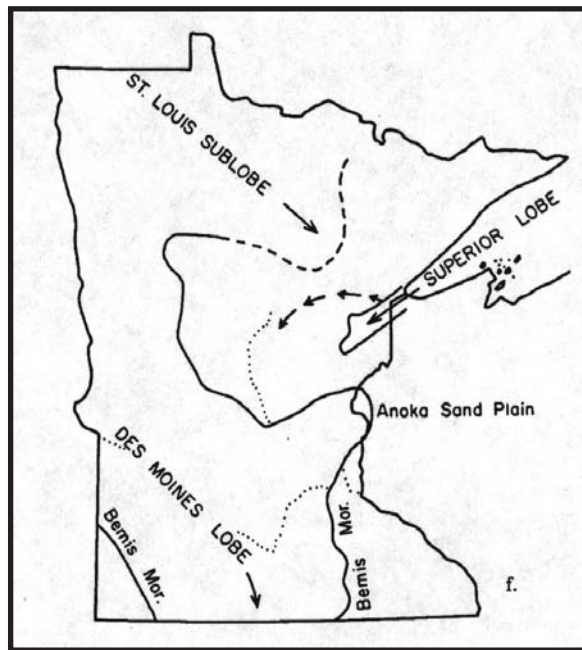
Retreat of the Superior Lobe was followed by advance of the Des Moines Lobe from the northwest during the Pine City phase, which reached its maximum extent in central Iowa about 14,000 years B.P. An end moraine near the city of Des Moines marks the terminal position of the ice lobe. During this advance, outwash channels were cut through portions of the St. Croix Moraine, forming sand and gravel deposits that reached the Mississippi River near Hastings.

The Grantsburg Sublobe, an offshoot of ice developed from the Des Moines Lobe, advanced from the southwest overriding the St. Croix Moraine between St. Cloud and St. Paul, reaching its terminus near Grantsburg, Wisconsin, by about 13,500 years B.P. (*Figure 6*). This short-lived advance was responsible for altering the geologic development of the Mississippi River valley in two important ways. First, outwash coming off the advancing lobe filled the Mississippi River valley with sand and gravel. The deposits would later be entrenched by glacial meltwater forming a series of flat-lying terraces between elevations of 800 and 820 feet along the valley. Second, advance of the lobe blocked the southward drainage of the Mississippi, resulting in the formation of glacial Lake Grantsburg.

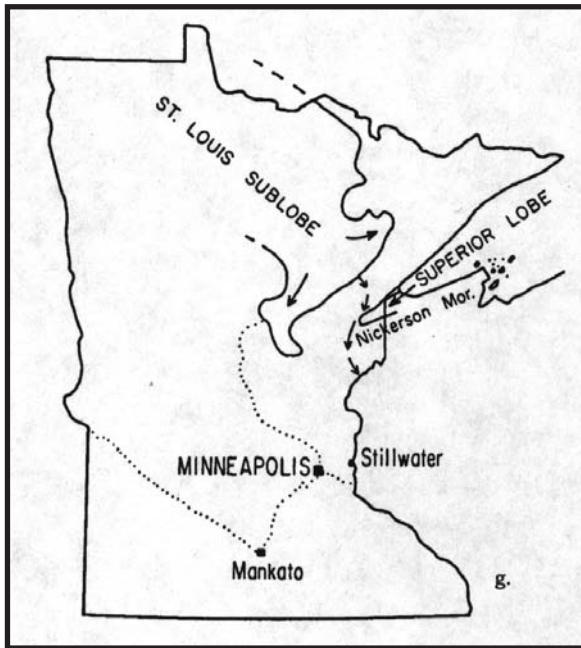
While the Grantsburg Sublobe occupied east central Minnesota and west central Wisconsin, meltwater draining south flowed into glacial Lake Grantsburg. A large delta was formed near Spooner, Wisconsin, as sediment-laden meltwater entered the head of the lake. The lake drained down the St. Croix River, eventually reaching the Mississippi River valley at Prescott, Wisconsin. As the Grantsburg Sublobe retreated to the southwest, meltwater drained around the outer (northeast) margin of the ice lobe, reworking the former lake bed and forming the Anoka Sand



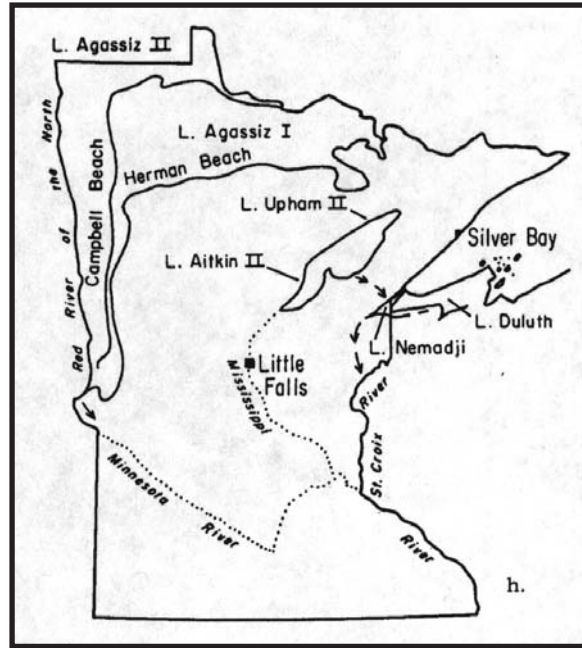
e) Split Rock-Pine City phase



f.) formation of the Anoka Sand Plain



g.) Nickerson-Alborn phase



h.) drainage of glacial Lake Duluth

FIGURE 5. Phases of glaciation in Minnesota (continued). Taken from Wright.<sup>16</sup>

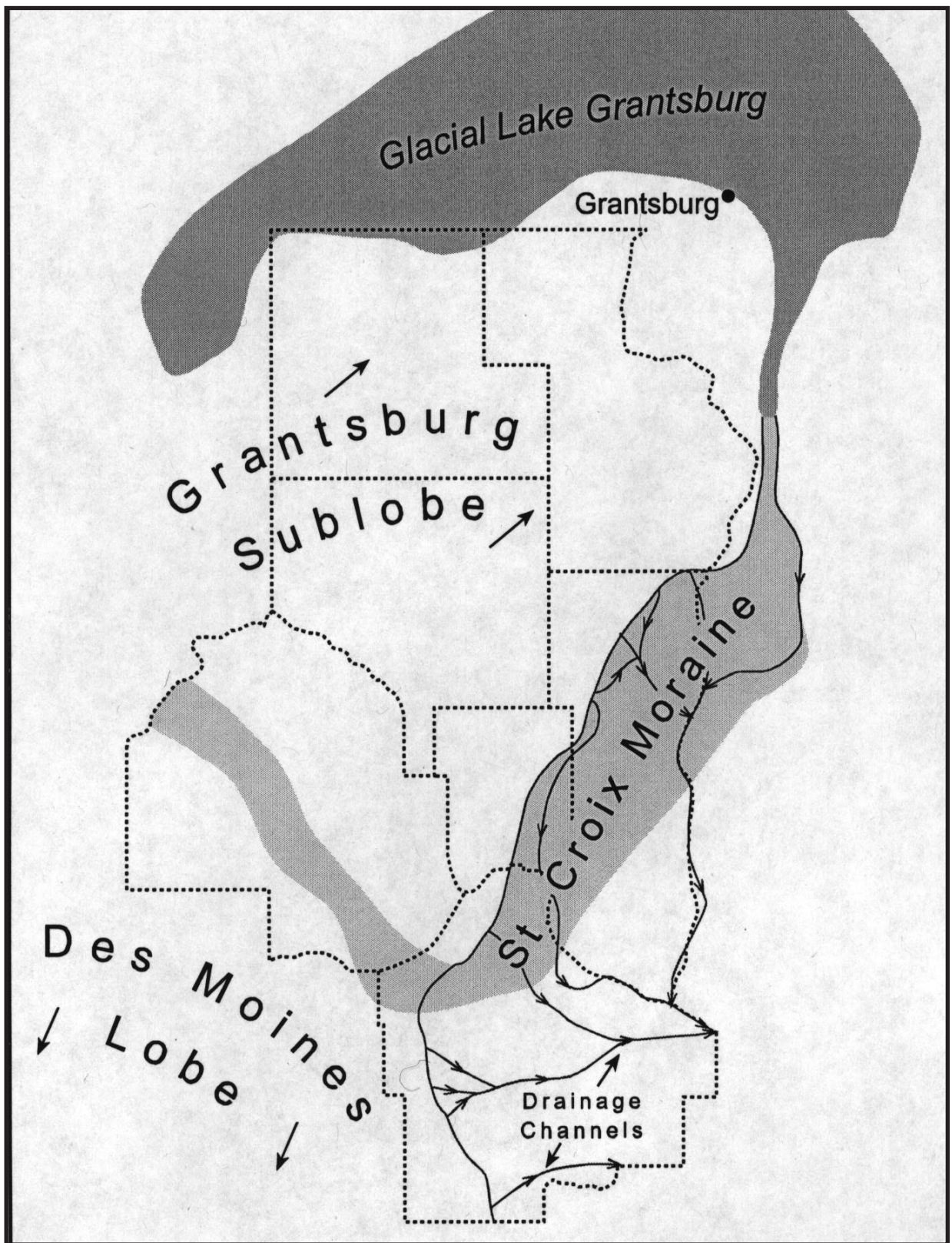


FIGURE 6. Advance of the Grantsburg Sublobe, an offshoot of the Des Moines Lobe, overriding the St. Croix Moraine blocking southward drainage of the Mississippi River, and forming glacial Lake Grantsburg. Drainage channels show paths taken by meltwater coming off the Grantsburg and Des Moines ice lobes. Redrawn from Meyer et al.<sup>21</sup>

Plain in east-central Minnesota (*Figure 5f*).

Farther south, retreat of the Des Moines Lobe was punctuated by a number of readvances, forming a series of discontinuous moraines in northern Iowa and southern Minnesota. By 12,300 years B.P., the Grantsburg Sublobe retreated back into Minnesota to join the Des Moines Lobe, which was retreating up the Minnesota River valley. A large braided meltwater stream developed along the retreating Grantsburg ice margin, forming a continuous blanket of sand and gravel along the present course of the Mississippi River above its confluence with the Minnesota River. As ice retreated further, the level of the Mississippi and Minnesota Rivers was established at an elevation of about 810 feet in the Twin Cities metropolitan area.

The last major glacial advance in Minnesota occurred during the Nickerson-Alborn phase when the St. Louis Sublobe, an eastward extension of the Des Moines Lobe, invaded north central Minnesota, forming the Culver Moraine. Retreat of the St. Louis Sublobe allowed glacial lakes Aitkin and Upham II to develop, ponded between the ice margin and the Culver moraine.

Lake Aitkin II most likely drained into Lake Upham II, which eventually drained down the St. Louis and Mississippi Rivers. At the same time, the Superior Lobe readvanced to the Nickerson-Thomson Moraines in northeastern Minnesota (*Figure 5g, 5h*). The Nickerson Moraine is marked by a belt of hummocky topography along the Carlton-Pine County line between Moose Lake and Holyoke. A broad outwash plain extends off the Nickerson Moraine southward where it coalesces into a fairly well defined channel along the Kettle River. The Kettle channel drained meltwater into the St. Croix River and then down to the Mississippi.

By 12,000 years B.P., all ice lobes that had previously covered the surface of Minnesota were in full retreat. The Des Moines Lobe was retreating rapidly northward up the Minnesota River valley. Ice then readvanced a short distance to form the Big Stone Moraine in west-central Minnesota about 11,900 years B.P. After the ice retreated

north of the divide that separates the Hudson Bay and Mississippi drainages, glacial Lake Agassiz came into existence. In northeastern Minnesota, the Superior Lobe retreated from the Nickerson ice margin into the Superior Lowland, initiating the formation of glacial Lake Duluth.

Drainage of sediment-free meltwater from glacial Lakes Agassiz and Duluth resulted in multiple downcutting events within the Mississippi River valley. A number of geologists have been active in working the drainage relationships of these lakes and their impact upon the landscape. Below is a summary of these works and how the events associated with glacial lake drainage affected the morphology of the upper Mississippi system.

Meltwater from Lake Agassiz drained down the River Warren into the Mississippi River valley. River Warren was named after G. K. Warren, the first commander of the St. Paul District, Corps of Engineers. Above St. Paul, the Mississippi River was flowing on top of the Platteville Limestone, which resisted the river's erosive force. Below St. Paul, the River Warren intercepted a preglacial bedrock valley of the Mississippi River that was filled with outwash up to the elevation of the Platteville Limestone. The discharge of River Warren was more than adequate to carry the sediment load supplied to it; therefore, the unconsolidated outwash sediment was rapidly eroded from the preglacial valley. Once the outwash was carried away, a waterfall formed where the River Warren plunged over the Platteville Limestone into the preglacial bedrock valley. The waterfall was named River Warren Falls in honor of the mighty river that was responsible for its formation.

Glacial ice, advancing again across the continental divide, caused a build up of sediment within the River Warren, the St. Croix, and presumably the Mississippi valleys approximately 11,700 years B.P. Glacial Lakes Agassiz and Superior reformed after 11,500 years B.P. as the ice again retreated beyond the continental drainage divide. Discharge of meltwater out of the lakes established a fairly active period of downcutting that lasted until approximately 10,800 years B.P.

One final advance of ice blocked eastern outlets and caused renewed downcutting within the Mississippi valley between 9,900 and 9,500 years B.P. This final episode is the last time that meltwater from glacial lakes flowed down the upper Mississippi River system north of Illinois. These events played a vital role in the Holocene evolution of the Mississippi valley.

**Early Holocene (9,500-7,000 years B.P.)** • The decrease in discharge through the Mississippi River following the drainage of glacial lakes and subsequent rerouting of meltwater through northern and eastern outlets initiated a stage of alluviation within the valley. The River Warren Falls began retreating up the Mississippi valley, as water eroded the soft St. Peter Sandstone that underlay limestone caprock (Figure 4). Below St. Paul the valley had been cut far below its present-day level, possibly up to 50 meters (about 163 feet) deep.<sup>22</sup> In response to the change in base level, tributary streams initially cut their channels to reach the level of the Mississippi. Sediments stored in tributary valleys were soon transported into the Mississippi River, resulting in a fairly active period of alluviation. More sediment entered the Mississippi from its tributaries than the big river could carry away. As a result, a number of tributaries built fan deltas into the Mississippi River, deflecting its course and altering the physiography of the floodplain.

A good example of a tributary delta occurs at the confluence of the Mississippi River with the Chippewa River in Pepin County, Wisconsin. The formation of the delta effectively dams the Mississippi River, forming Lake Pepin. Zumberge proposed that Lake Pepin once extended upstream to St. Paul, based on the existence of clay deposits found in borings taken during the construction of the Robert Street Bridge in St. Paul.<sup>23</sup> Sediment entering the river above Lake Pepin has built a delta within the Mississippi that is slowly moving downstream. This delta begins at Hastings and extends to the head of Lake Pepin, south of Red Wing.

Equilibrium between the Mississippi River and its tributaries began to establish itself by 8,000 years B.P. By this

time, the River Warren Falls had reached the Minnesota River valley, where it split into two parts. The River Warren Falls continued to retreat up the Minnesota River valley an additional two miles, where it intersected a buried valley of the preglacial Mississippi that died out. St. Anthony Falls developed at the confluence of the Minnesota River near Fort Snelling and retreated up the valley of the Mississippi (Figure 4).

**Middle Holocene (7,000-3,500 years B.P.)** • Slow alluviation along the Mississippi River continued into the middle Holocene. Vegetation was well established on upland areas by this time. Therefore, the change in upper midwestern rivers was most likely related to climatic effects on river discharge rather than changes in vegetation.<sup>24</sup>

Geomorphic processes acting in the valley were variable along the entire stretch of the upper Mississippi River. The upper reaches were characterized by vertical accretion (built up) of sediment, while lateral channel migration and incision into previously deposited sediment were occurring in downstream reaches.

As the middle Holocene progressed, climatic changes would again alter the processes acting within the valley. Cooler temperatures and increased precipitation began to dominate the regional climate, which may have initially increased runoff. In response, active lateral channel migration and incision dominated fluvial processes acting in the valley.

**Late Holocene (3,500 years B.P. - A.D. 1850)** • Much of the present-day surface morphology of the Mississippi River floodplain is the result of fluvial activity occurring during the late Holocene. However, fluvial processes varied with location along the valley. Vertical accretion dominated various portions of the valley, while lateral channel migration, or cut and fill sequences, dominated other parts. As a result, the appearance of floodplain features within the valley varies, depending on location.

During the late Holocene, climate was still a major driving force for geomorphic processes. The regional cli-



mate continued its trend toward cooler temperatures and increased precipitation. By this time, vegetation and soils were most likely well developed on landforms not subject to inundation by floodwaters. Lateral channel migration, or cut and fill cycles, dominated these portions of the valley.

Geomorphic studies conducted in various portions of the upper Mississippi River valley indicate that the present-day position of the river channel changed little during the late Holocene.<sup>25</sup> This realization is important for several reasons. First, active fluvial processes would be confined to a limited channel area. As a result, the potential for erosion of landforms would be greatest near the active channel margin. Second, landforms within the floodplain away from the main channel would be subject to vertical accretion of sediment and preservation of natural features. This has implications for both the environmental and cultural resource records. Third, landforms that are topographically higher along the valley margin would have been less prone to flooding and the burial of previously developed surfaces.

It is difficult to assess the major changes that occurred within the floodplain of the upper Mississippi River valley during the late Holocene, without absolute chronological dates. Many of the changes occurring within the area were related to shifts in regional climatic patterns, which had a direct influence on geomorphic processes. Vertical accretion of sediment and forward movement of alluvial fans/deltas dominated portions of the valley near the confluence of tributary streams. Areas away from tributaries were most likely subjected to lateral channel migration, resulting in reworking of previously deposited sediment. Erosional processes would have been dominant near the active channel, while constructional processes would have been active in backwater areas on the floodplain.

**A.D. 1850 - Present** • Land clearing efforts for the development of agriculture began during the mid-1800s within and adjacent to the MNRRRA corridor. Erosion of topsoil from exposed fields increased the influx of sediment into the Mississippi River, especially in areas near the confluence

of major tributary streams. Review of Mississippi River Commission maps provides evidence of the changes that have occurred.<sup>26</sup> Accumulations of up to two meters of post-settlement alluvium may occur on the floodplain in the southern reaches of the MNRRRA corridor.

With the increased awareness of soil erosion along the land areas adjacent to the upper Mississippi valley and the development of modern agricultural equipment, farmers began to use improved farming techniques. By the 1930s farmers increasingly practiced contour plowing, conservation tillage, and no-till planting. Some farmers left their fields fallow to increase the soil's nutrient capacity. These efforts greatly reduced topsoil erosion, decreasing sediment loads entering the Mississippi River.

Humans have changed the landscape of the valley and the flow of the Mississippi River in other ways, some as profoundly as the glaciers. Overall, however, humans have adapted to and developed around the river's geologic foundation. This will become clear in each subsequent chapter.

## Prominent Natural Features

The Mississippi River valley is a significant natural feature in its own right. However, a number of individual features found along the river valley through the MNRRRA corridor are notable. A brief description of each locality is presented below.

**Glacial Terraces** • Three prominent terraces occur along the course of the Mississippi River in the MNRRRA corridor. Each formed as a result of late glacial meltwater drainage along the major rivers in the MNRRRA corridor. The Richfield Terrace is the highest terrace surface, ranging in elevation from 890 feet above mean sea level (amsl) in the northwest corner of the MNRRRA corridor to 840 feet amsl in the southeast corner. The city of Minneapolis is built largely upon this terrace surface.

Inset below the Richfield Terrace is the Langdon Terrace, which has the widest range of distribution throughout the corridor. Elevation of the Langdon Terrace ranges from 850 amsl in the northwest corner of the MNRRRA corri-

dor to 800 feet amsl in the southeast corner. The Langdon Terrace exhibits a tremendous amount of variability in its sedimentary characteristics along the valley. Between St. Anthony Falls and Daytons Bluff the terrace developed on top of the underlying Platteville Limestone. Terrace sediments are only a few feet to tens of feet thick. Throughout the rest of the area, where preglacial erosion removed much of the bedrock, the terrace consists of 100 feet or more of sand and gravel. The cities of South St. Paul and Cottage Grove are built largely upon this terrace surface.

The Grey Cloud Terrace is the lowest terrace present along the Mississippi River in the MNRRA corridor. The Grey Cloud Terrace occurs only south of St. Paul and ranges in elevation from 750 to 700 feet amsl. Like the Langdon Terrace, it formed partially over bedrock. At Newport, the terrace consists of sediments a few feet thick on top of the Prairie du Chien Group. However, at Grey Cloud Island the terrace consists of a thick sequence of sand and gravel left as an erosional remnant of the once higher Langdon Terrace surface.

**St. Anthony Falls** • The Mississippi River cascading over the Platteville Limestone at St. Anthony Falls exemplifies the power of fluvial processes operating upon the land surface. Long revered for its natural beauty, the waterfall was once located at the confluence of the Mississippi and Minnesota Rivers but migrated upstream to its present location. The natural state of the falls has been modified by the construction of milling and hydroelectric power structures and a lock and dam system.

**Shadow Falls** • At Shadow Falls, a small tributary valley on the east bank of the Mississippi, in St. Paul, is one of the best exposed and easily accessible outcrops of the St. Peter Sandstone, Glenwood Shale, Platteville Limestone, and Decorah Shale in the Twin Cities. A variety of invertebrate fossils, including conodonts and trilobites, can be collected here.

**Minnehaha Falls** • Formed in a manner similar to St. Anthony Falls, Minnehaha Falls offers the observer an

opportunity to view a waterfall in its natural state. The location of the falls within Minnehaha Park provides ready access to explore the bedrock geology of the Twin Cities in a small tributary to the Mississippi River.

**Mississippi-Minnesota Rivers Confluence** • Bdo-te, or confluence, as the Mdewakanton Dakota call it, is where the Mississippi and Minnesota rivers converge. Created by the discharge of meltwater from glacial Lake Agassiz down glacial River Warren, the confluence has been a gathering place for people throughout several millennia. Pike Island separates the two rivers where the valleys join, and the physical confluence is one mile downstream. Steep bedrock bluffs covered with a variable thickness of glacial sediment characterize the valley here. The confluence offers the opportunity to explore the natural riches contained in two very different river valleys.

**Twin City Clay Pit/Lilydale Regional Park** • Exposures of the Platteville Limestone, Decorah Shale, and lower Cummingsville Formation offer excellent fossil hunting at the Twin City Clay Pit/Lilydale Regional Park. In addition to bedrock geology, exposures of glacial till deposited by both the Superior and Des Moines Lobes can be found upon diligent search. The Decorah Shale was formerly mined at this location for clay used in the manufacture of bricks.

**Daytons Bluff/Mounds Park** • The St. Peter Sandstone, Glenwood Shale, and Platteville Limestone are exposed along Warner Road in Daytons Bluff. Overlying the bedrock is a thin cover of glacial sediment deposited by the Superior Lobe during late-Wisconsin glaciation. At the base of the bluffs is an apron of colluvium derived from sediment weathering and eroding of bedrock. Six mounds, built by Native American inhabitants some 2,000 years ago, lie on top of the bluff. This location offers an excellent example of combined natural and cultural resources.

**Battle Creek Park** • The uppermost 50 feet of the St. Peter Sandstone is exposed within the valley of Battle Creek Park.

It is one of the best examples of a preglacial valley developed in bedrock that escaped being filled with glacial sediments in late-Wisconsin time.

***Pigs Eye Lake*** • Pigs Eye Lake was a naturally occurring open body of water within the floodplain of the Mississippi. At one time it may have been part of Lake Pepin, which is believed to have extended to St. Paul during the early Holocene. The lake now serves as a haven for a variety of wildlife, including birds, fox, beaver, raccoon, and similar floodplain dwellers.

***Lower Grey Cloud Island*** • A terrace remnant related to late glacial trenching of the Mississippi River, Lower Grey Cloud Island is composed of stratified sand and gravel deposits overlain by fine sand. The island has many mound groups constructed by the river valley's early inhabitants.