GEOLOGIC HISTORY OF MINNESOTA RIVERS

Minnesota Geological Survey
Educational Series — 7

Minnesota Geological Survey
Priscilla C. Grew, *Director*

Educational Series 7

GEOLOGIC HISTORY OF MINNESOTA RIVERS

by

H.E. Wright, Jr.

Regents' Professor of Geology, Ecology, and Botany (Emeritus), University of Minnesota

TRAP, DALLES OF THE ST. CROIX.

University of Minnesota
St. Paul, 1990

Cover: An early portrayal of St. Anthony Falls on the Mississippi River in Minneapolis. The engraving of a drawing by Captain E. Eastman of Fort Snelling was first published in 1853; it is here reproduced from the **Second Final Report of the Geological and Natural History Survey of Minnesota,** *1888.*

Several other early views of Minnesota rivers reproduced in this volume are from David Dale Owen's **Report of a Geological Survey of Wisconsin, Iowa, and Minnesota; and Incidentally of a portion of Nebraska Territory,** *which was published in 1852 by Lippincott, Grambo & Company of Philadelphia.*

ISSN 0544-3083

FALLS OF KETTLE RIVER.

CONTENTS

1 . . . . INTRODUCTION

1 . . . . PREGLACIAL RIVERS

5 . . . . GLACIAL RIVERS

17 . . . . POSTGLACIAL RIVERS

19 . . . . RIVER HISTORY AND FUTURE

20 . . . . REFERENCES CITED

GEOLOGIC HISTORY OF MINNESOTA RIVERS

H.E. Wright, Jr.

INTRODUCTION

A GLANCE at a glacial map of the Great Lakes region (Fig. 1) reveals that all of Minnesota was glaciated at some time, and all but the southeastern and southwestern corners were covered by the last ice sheet, which culminated about 20,000 years ago. Thus all the existing river courses in the state, except the Mississippi River below Hastings, are postglacial in origin. Older river courses were overridden by the ice sheet and buried by glacial deposits. During glaciation, meltwater streams were numerous—some of them flowed under the ice itself, and most of the valleys they cut were abandoned when the ice retreated. Further changes occurred during ice retreat, such as the formation of large glacial meltwater lakes immediately in front of the ice (proglacial lakes), which were drained by streams much larger than their postglacial successors. This account describes the nature of some of the preglacial, glacial, and postglacial rivers in Minnesota.

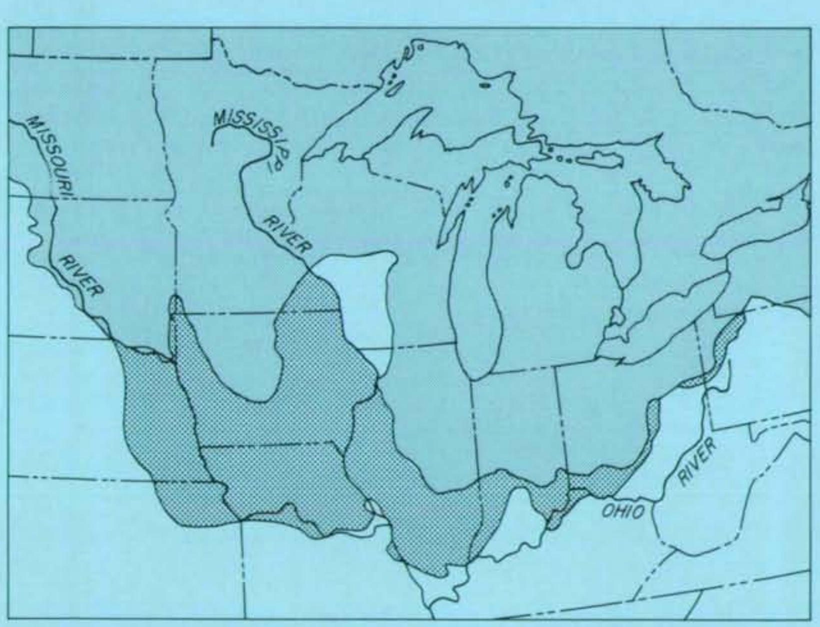


FIGURE 1.

Glaciation in the Great Lakes region. The Laurentide ice sheet, the last glacial advance in the region, reached its greatest extent about 20,000 years ago (light gray). The areas shaded dark gray represent the southern limit of earlier glacial ages. Southwestern Wisconsin and northwestern Illinois were never covered by an ice sheet.

PREGLACIAL RIVERS

THE CONTROL OF CONTINENTAL GLACIATION on the major river pattern in the United States can be envisioned by noting the courses of the Ohio and Missouri Rivers, which basically delineate the glaciated region (Fig. 1). Thus on a continental scale, the Laurentide ice sheet bulged southward into the central lowlands occupied by the Great Lakes basins. The movement of individual ice lobes was directed by these basins, which were converted from open, stream-drained lowlands to closed basins

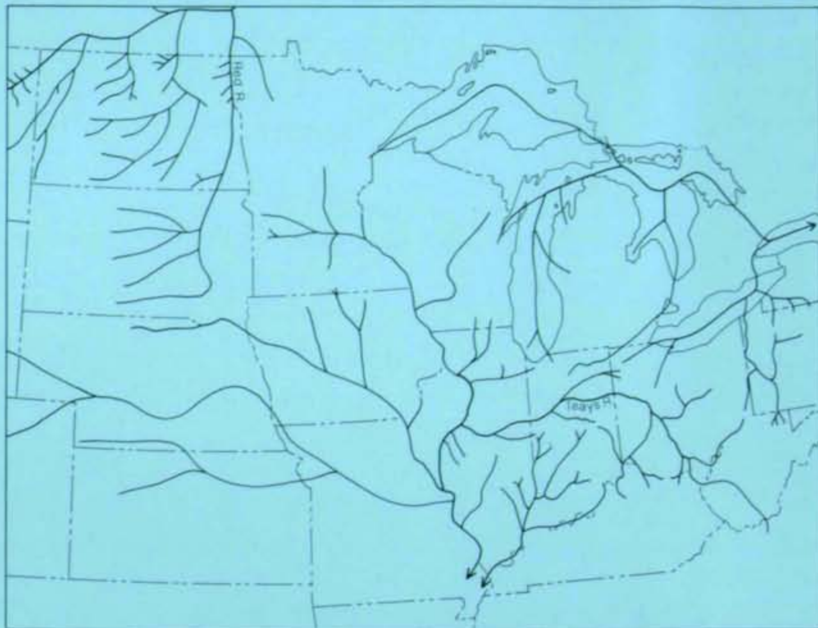


FIGURE 2.

Sketch map of preglacial river courses in the north-central United States. See Figure 3 for a more detailed map of southern Minnesota. Adapted from Bray (1985).

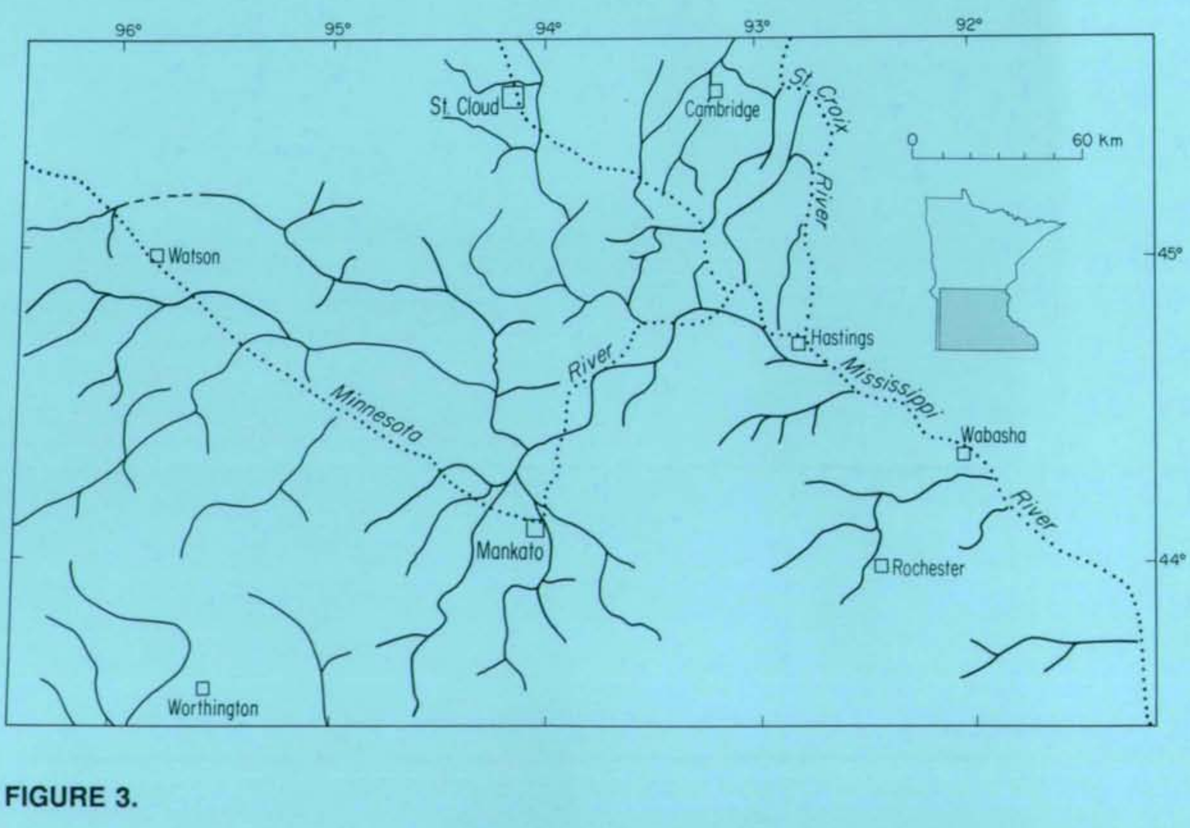


FIGURE 3.

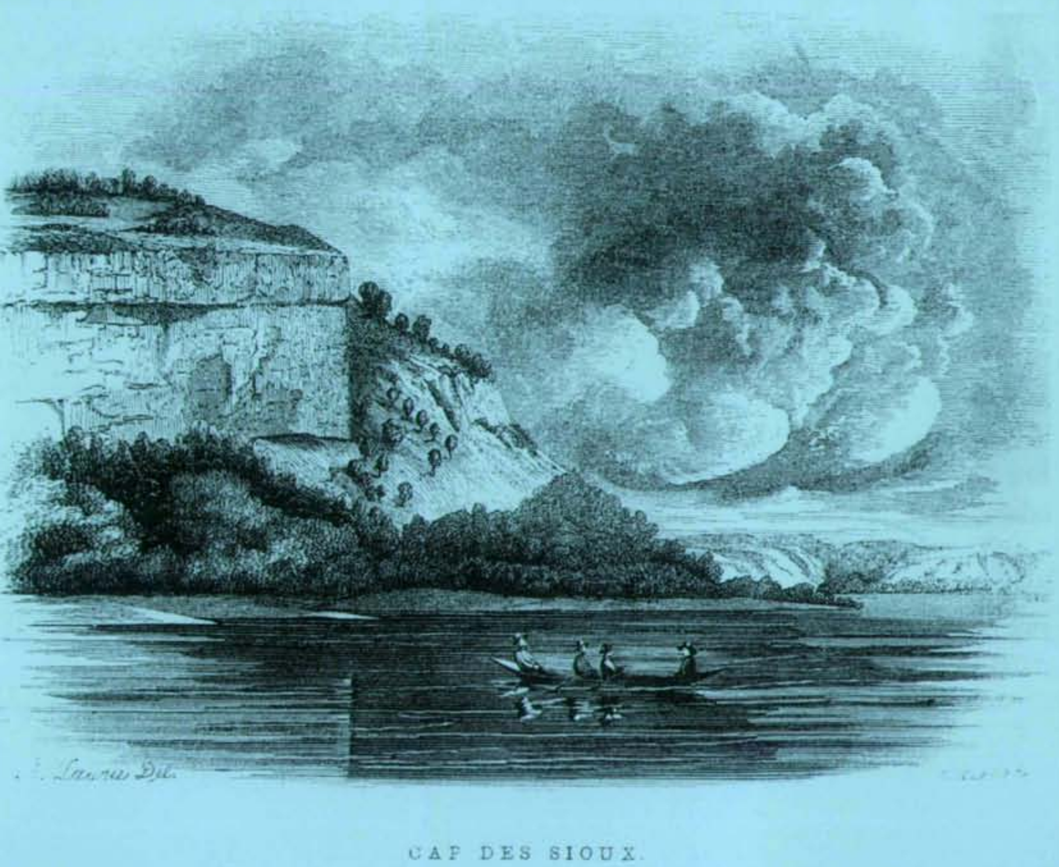
Preglacial (and interglacial) river valleys cut in the bedrock of southern Minnesota, identified from well records. The dotted lines show the major modern river courses. Generalized from Olsen and Mossler (1982).

by deep glacial erosion as well as by damming at the southern ends through the deposition of moraines (mounds or ridges of glacially eroded rock debris).

The river pattern in this region prior to glaciation (Fig. 2), although incomplete, includes numerous streams flowing eastward across the Great Plains into the eastern Dakotas. Some of these streams were presumably tributary to the lowland now occupied by the Red River of the North, and thus drained to Hudson Bay. In the eastern Great Lakes region, the ancient Teays River cut across central Ohio, Indiana, and Illinois. It filled the role of the modern Ohio River by focusing the surface drainage of these states and of the Appalachian Plateau.

Within the southern half of Minnesota a similar compilation shows that most former streams have no relation to the present courses (Fig. 3). The modern Minnesota River, for example, is offset a substantial distance from an earlier stream of similar size. It did not join the preglacial Mississippi River at the same place as today but rather crossed through Dakota County to Pine Bend.

For the Minneapolis–St. Paul area, a map in greater detail (Fig. 4) shows a whole set of bedrock valleys filled with glacial debris that have no relation to the present courses of the Mississippi, Minnesota, and St. Croix Rivers. These old courses were not all created at the same time; during each of several interglacial intervals the major rivers adopted different courses and cut deep gorges similar to those formed in postglacial time. Many of these old courses



CAP DES SIOUX.

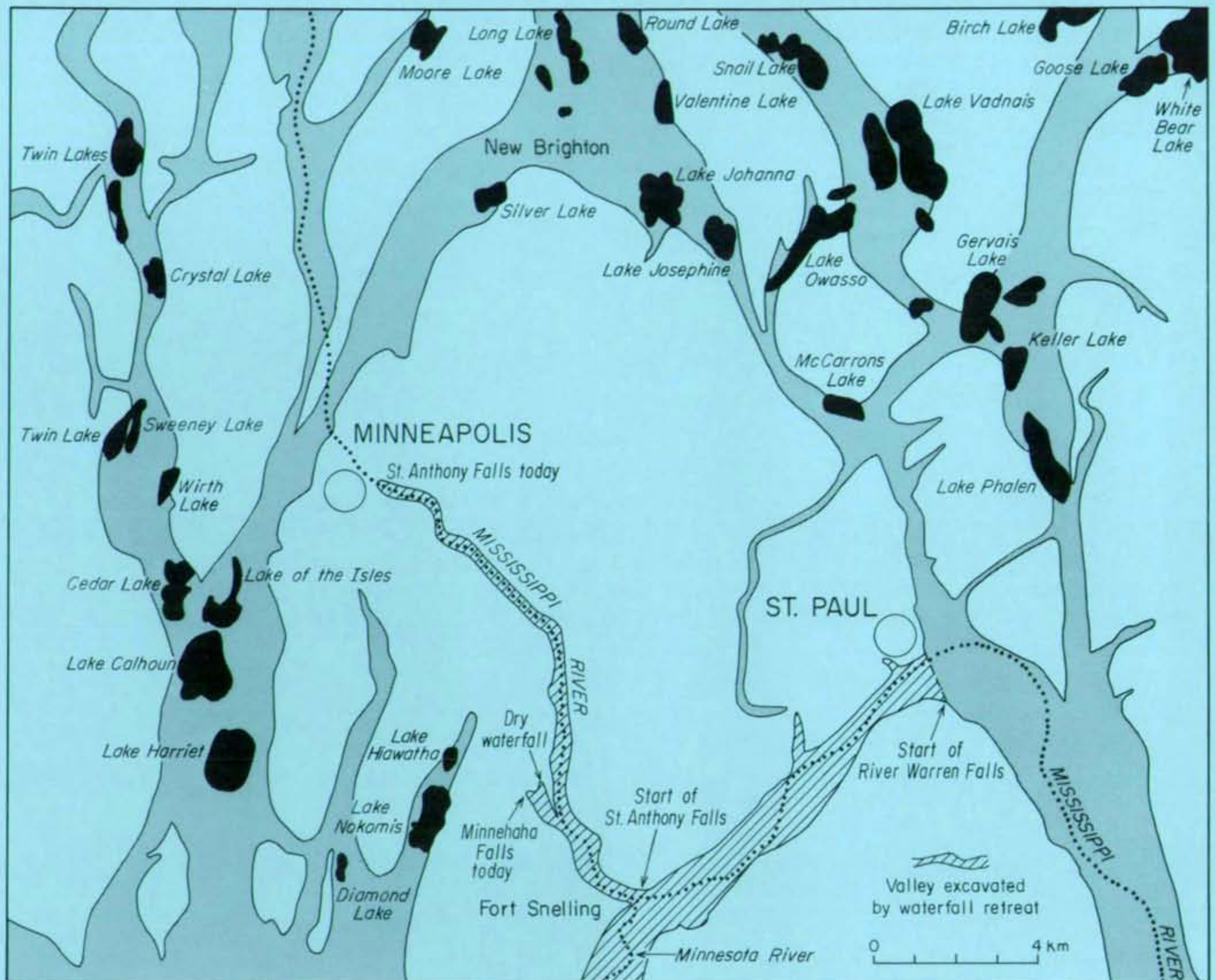


FIGURE 4.

Pre- and interglacial river valleys (gray) in the Minneapolis–St. Paul area, identified from well records. The lakes located over the valleys represent buried masses of glacial ice relatively free of rock debris, which when melted formed depressions that filled with water. The modern Mississippi and Minnesota Rivers are shown as dotted lines. Modified from Wright (1972).

are marked on the surface by strings of lakes: for example, the Cedar Lake/Lake Calhoun/Lake Harriet string in western Minneapolis, or the Snail Lake/Lake Vadnais/Lake Phalen string in St. Paul. These lakes represent relatively clean portions of the ice that covered the area, whereby the rest of the ice contained large amounts of rock debris. When the ice eventually melted, the surface collapsed, producing depressions that filled with water to make the lakes. Radiocarbon dating of the organic sediments at the bottom of such lakes indicates that the buried ice in that region lasted until as late as about 12,000 years ago.

GLACIAL RIVERS

MINNESOTA WAS COMPLETELY COVERED by an ice sheet several times during the glacial period. There were several different ice lobes involved from the last glacial maximum in the Great Lakes region (about 20,000 years ago) to about 11,000 years ago, by which time the ice front had retreated into Canada, except for a still-active ice lobe in the Lake Superior basin (Fig. 5).

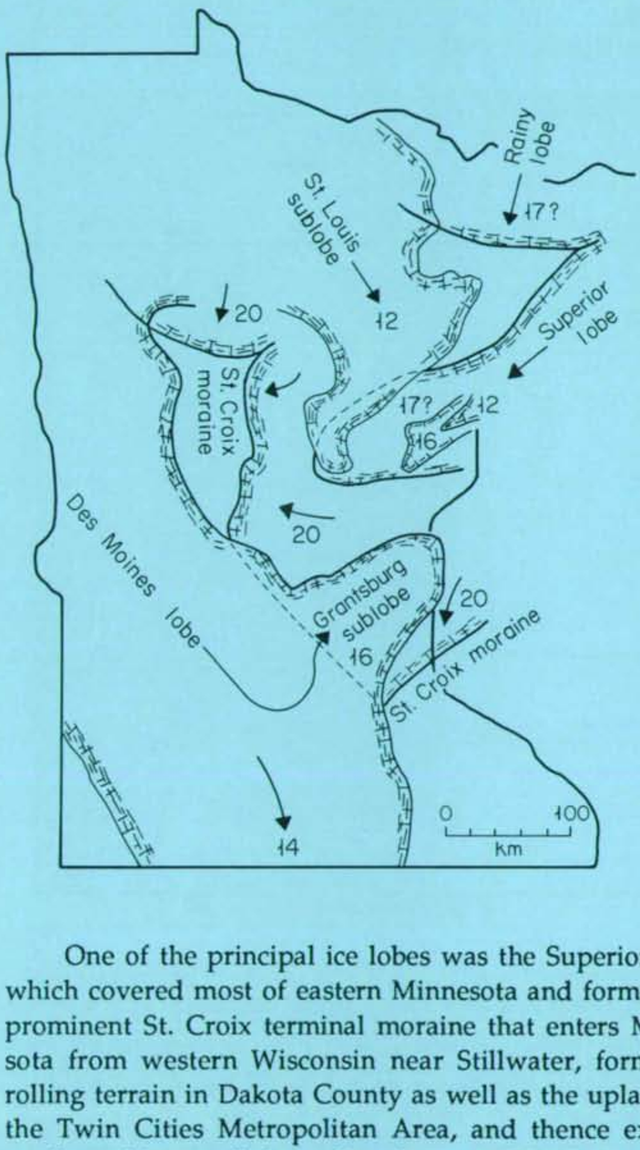


FIGURE 5.

Lobes of the Laurentide ice sheet that invaded Minnesota from different directions during the last (late Wisconsinan) glaciation. The numbers indicate rough estimates for the date of each ice advance in thousands of years before present. Simplified from Wright (1972).

One of the principal ice lobes was the Superior lobe, which covered most of eastern Minnesota and formed the prominent St. Croix terminal moraine that enters Minnesota from western Wisconsin near Stillwater, forms the rolling terrain in Dakota County as well as the uplands in the Twin Cities Metropolitan Area, and thence extends northward (generally bounding the upper Mississippi River valley on the west) to near Walker in Cass County. This ice lobe remained at this position for a long time under stable climatic conditions; it was supplied by continued snowfall farther to the northeast and was subject to melting near its edge. Water that accumulated at the base of the ice became concentrated in major streams that cut prominent valleys (tunnel valleys)—originally as much as one to two kilometers wide and ten to thirty meters deep, which are now occupied in places by lakes and peatlands (Fig. 6). These streams flowed at high velocity because of the high

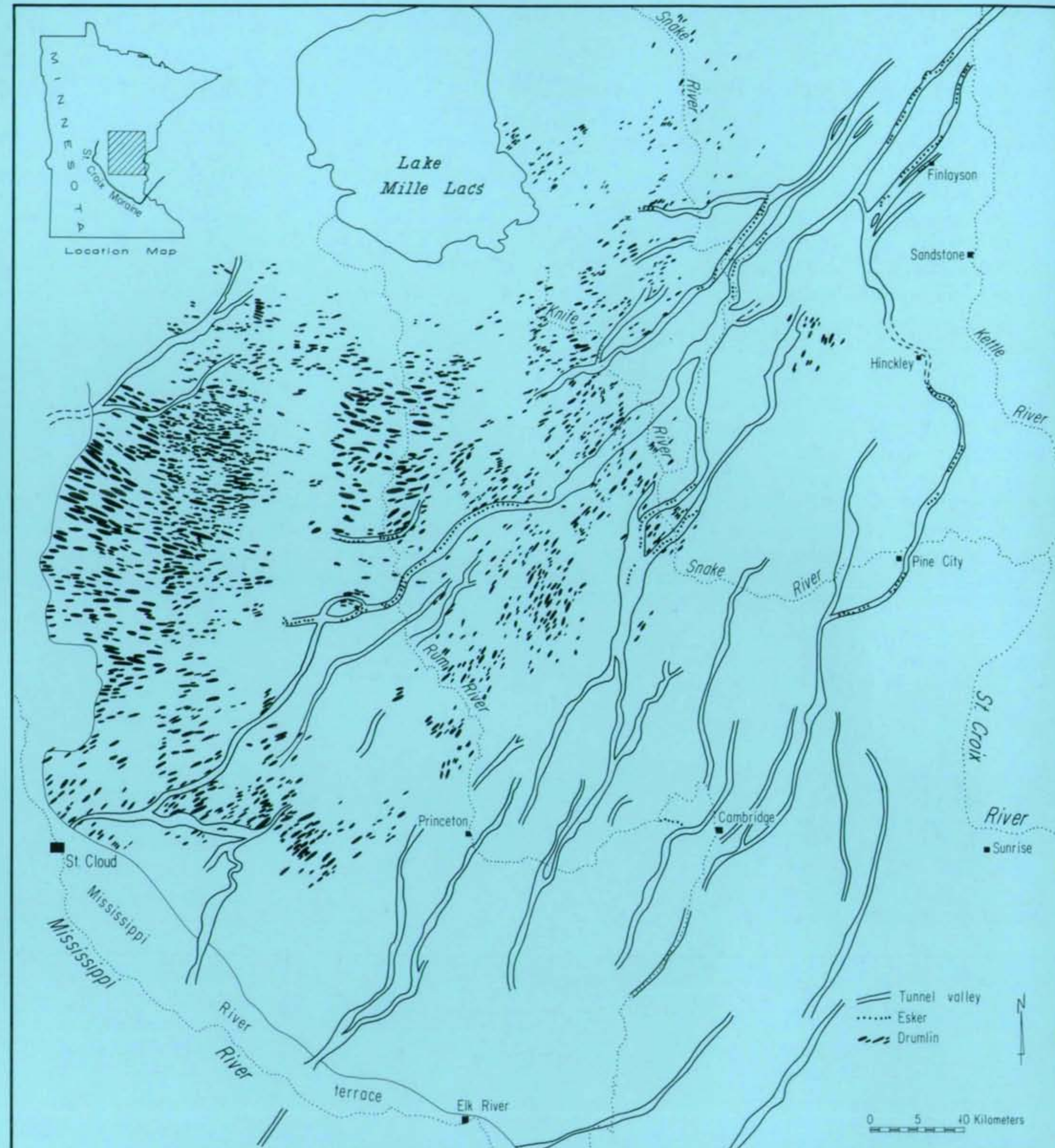


FIGURE 6.

Tunnel valleys formed beneath the Superior lobe ice in east-central Minnesota. The fan-shaped distribution reflects the hydrostatic gradient and thus the surface slope and general form of the ice lobe. Modified from Wright (1972).

hydrostatic pressure created by the great thickness of the ice, as well as because of the great quantities of meltwater. The group of about twelve tunnel valleys in east-central Minnesota (Fig. 6) forms a fan-shaped pattern trending generally southwest. Note that the modern drainage of this area is southeastward, consistent with the regional slope (Wright, 1973). The southwestward trend of the tunnel valleys reflects the southwestward gradient of the ice surface (and thus the hydrostatic gradient).

When the ice thinned and retreated, the velocity of the subglacial streams decreased, and the flowing water could no longer keep open the wide tunnel valleys against the pressure of the moving ice, nor could it carry all the rock debris eroded from the floor. The consequence was the buildup of gravel and sand deposited on the floor of the diminished stream course in the tunnel. When the ice all melted what remained was a linear ridge of gravel and sand that is called an esker (Fig. 7).

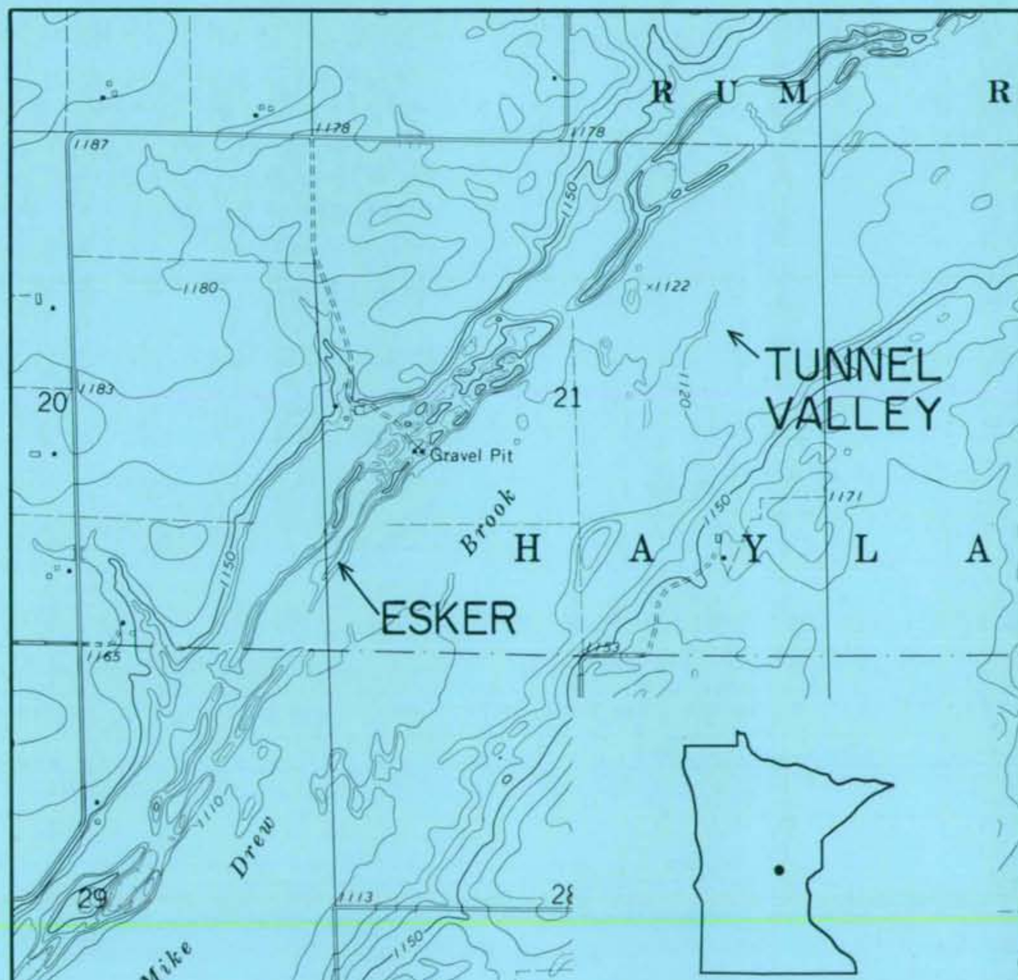


FIGURE 7.

Topographic map of a segment of the tunnel valley north of Milaca, Mille Lacs County. The narrow linear double ridge on the north side of the valley floor is an esker, formed by deposition of sand and gravel on the floor of the subglacial valley when the flow of water had diminished and the valley had become much smaller. The valley here is about one kilometer broad, and the rim is about twelve meters high. An unknown amount of peat is beneath the floor. From U.S. Geological Survey 7.5-minute Bock quadrangle (1968).

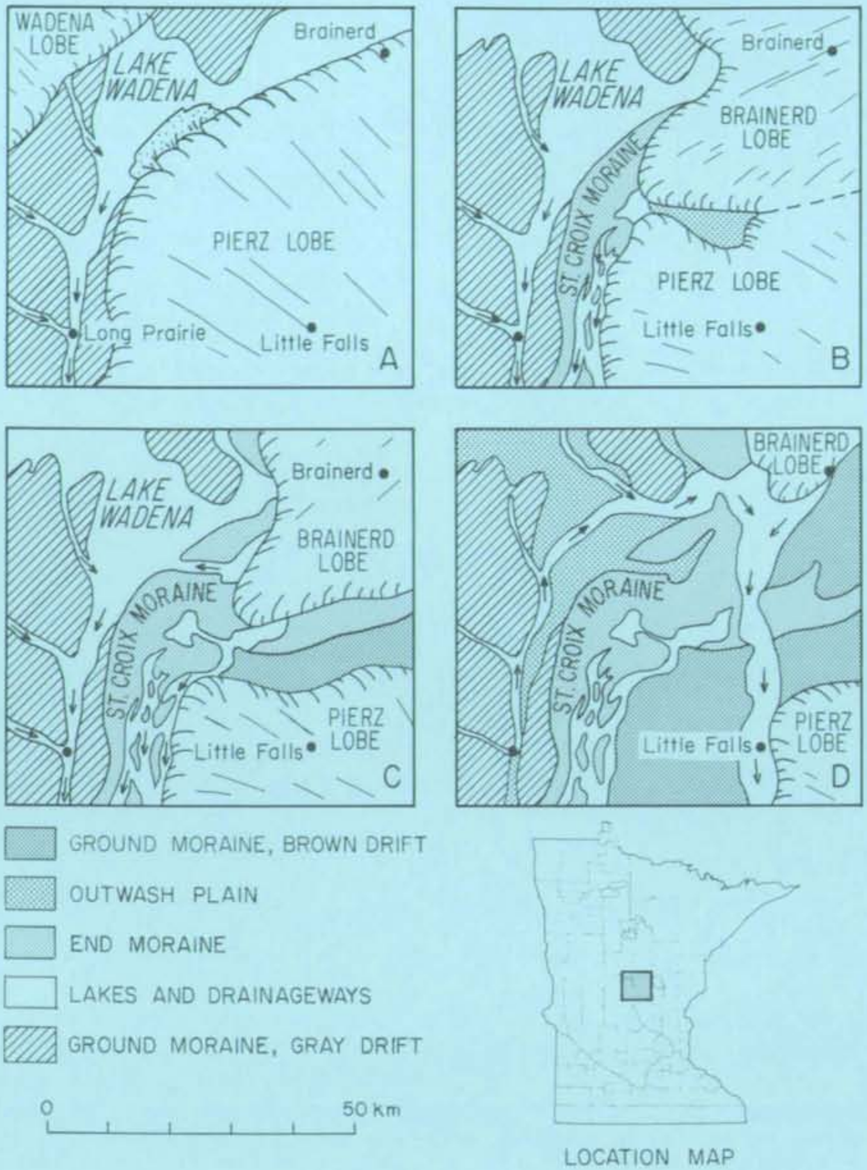


FIGURE 8.

Early stages in the development of the Mississippi River in the segment downstream from Brainerd, Crow Wing County. The southward drainage down the Long Prairie River west of the St. Croix moraine (stages A–C) was blocked on the south by the Grantsburg sublobe (not shown on figure), and the drainage direction reversed (stage D). At the same time, the eastern ice withdrew to open a course for the incipient Mississippi River. Lake Wadena was probably an outwash plain rather than a lake. Modified from Schneider (1961).

The upper Mississippi River first began to form as the Superior lobe retreated. Successive channels can be traced in the segment from the Brainerd area south to Little Falls in central Minnesota (Fig. 8). Meltwater streams emerging from either the base or the surface of the ice spread gravel and sand in outwash plains and valley deposits. The largest of these areas is the Anoka sand plain, which spread across east-central Minnesota as the Mississippi River was diverted eastward by the Grantsburg sublobe, which advanced from the west (Fig. 9a). After this temporary diversion, the outwash sand was funneled down the Mississippi River through the Minneapolis–St. Paul area (Fig. 9b) and downstream to Iowa and beyond. It formed what is now a distinctive terrace above the present river gorge, evident as the great flats at the airport near Fort Snelling and the patch at the mouth of the Cannon River (a tributary of the Mississippi) north of Red Wing. This flood of outwash sediment along the Mississippi River south of St. Paul

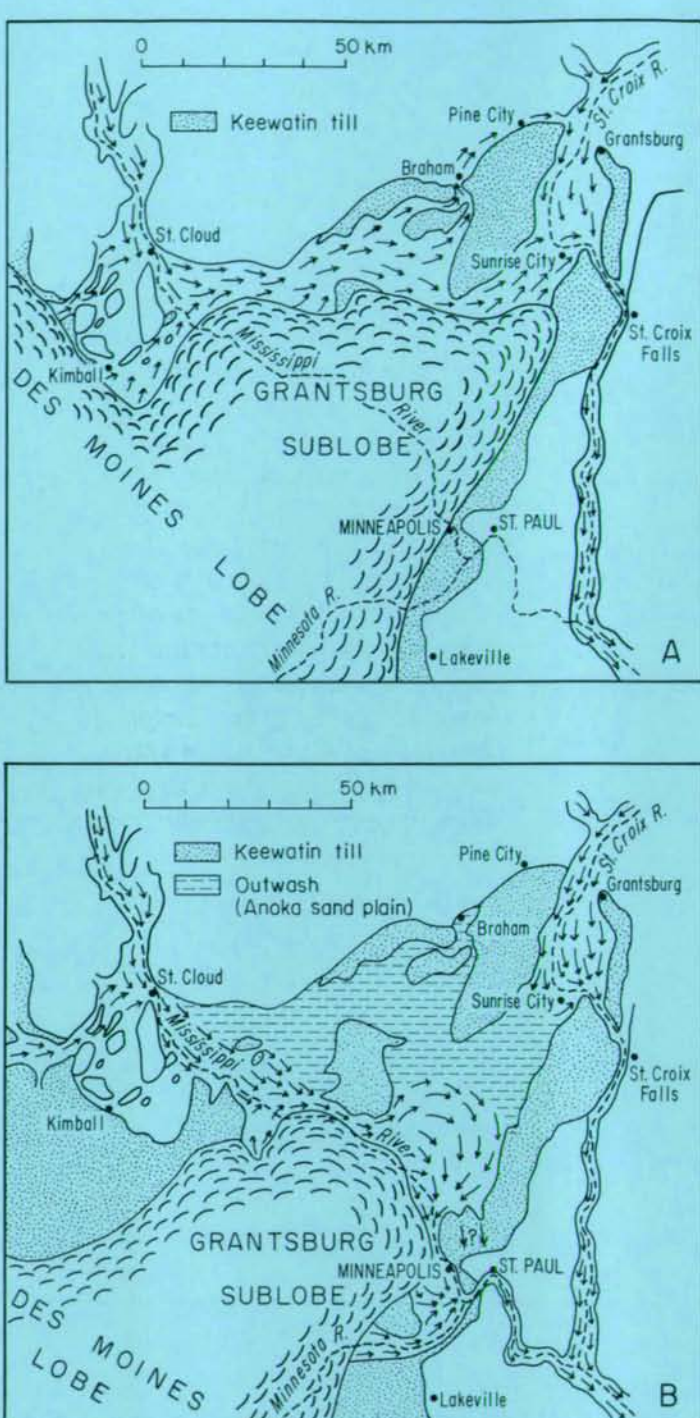


FIGURE 9.

Formation of the Anoka sand plain in east-central Minnesota by the diversion of the Mississippi River around the wasting Grantsburg sublobe, which deposited the "Keewatin till". The courses of modern rivers are shown as dashed lines. Modified from Cooper (1935).

caused backflooding up the tributaries, producing the flat floors that characterize the lower reaches of these streams, and even causing flooding of low drainage divides between tributaries, thereby leaving islands of uplands representing the former divides. The Frontenac bluffs along Lake Pepin may have been isolated in this way (Fig. 10).

FIGURE 10.

Isolation of the bluffs of Frontenac State Park in Goodhue County by the splitting of the Mississippi River during deposition of glacial outwash sediment, which flooded tributaries and low drainage divides. The northern branch (Lake Pepin course) was downcut more deeply during the River Warren stage and captured the flow from the southern branch, which is now partially filled with marshes and occupied by the main highway and railroad. Reduction from U.S. Geological Survey 7.5-minute topographic maps of the Maiden Rock and Bay City quadrangles (1974).

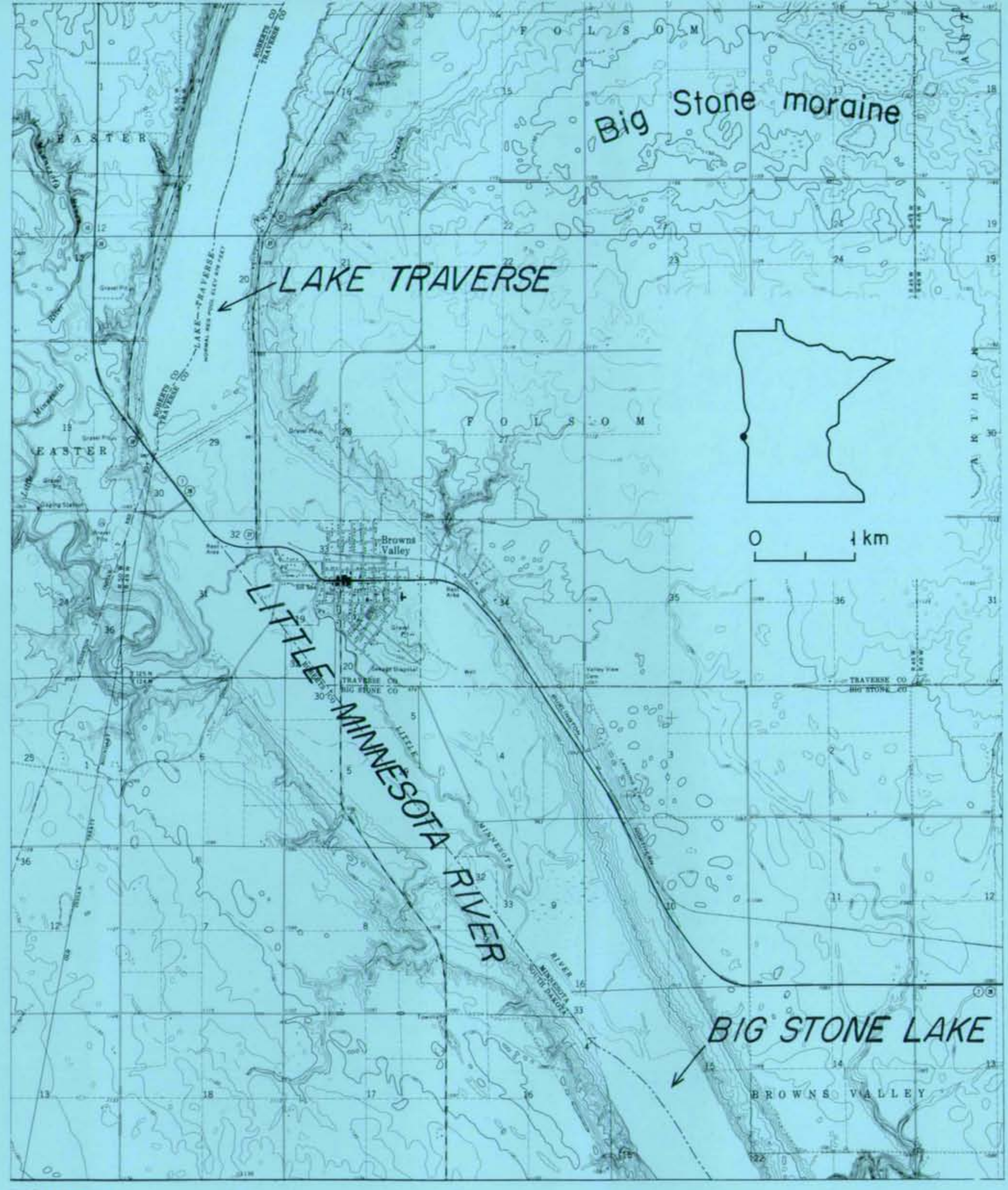


FIGURE 11.

The Glacial River Warren gorge near Browns Valley, formed by the outlet waters of Glacial Lake Agassiz. The narrow terrace that carries the railroad southeast of Browns Valley is covered with huge boulders, which probably formed a pavement across the gorge. The pavement was subsequently breached by increased discharge as the ice retreated and Lake Agassiz enlarged. After the end of the River Warren discharge, the Little Minnesota River from the west deposited an alluvial fan across the gorge at Browns Valley, thereby forming Lake Traverse and reversing the drainage of that part of the gorge. The city of Browns Valley was built on this fan. Big Stone Lake was similarly dammed by a tributary farther downstream. Reduction from U.S. Geological Survey 7.5-minute topographic maps of the Browns Valley and Peever NE quadrangles (1977).

Glacial River Warren

AS THE DES MOINES LOBE RETREATED to the northwest, its outwash stream established a new course across the lowest till-covered land it had left behind—a course different from the preglacial course but one that ultimately became the Minnesota River Valley of southwestern Minnesota. When this ice lobe retreated across the continental drainage divide near Browns Valley close to the South Dakota border (Fig. 11), a lake formed between the divide and the ice front. This was Glacial Lake Agassiz, which drained southward across the continental divide to form Glacial River Warren.

The erosion of the River Warren gorge near the Lake Agassiz outlet proceeded in steps, each one represented now by a terrace (Fig. 11). In the outlet area, the glacial till of the low Big Stone moraine, which dammed Lake Agassiz on the south, contained many large granite boulders. These were washed out of the till by the outlet waters to form a kind of pavement across the channel, which prevented further downcutting. The lake thereby was stabilized, and it formed a

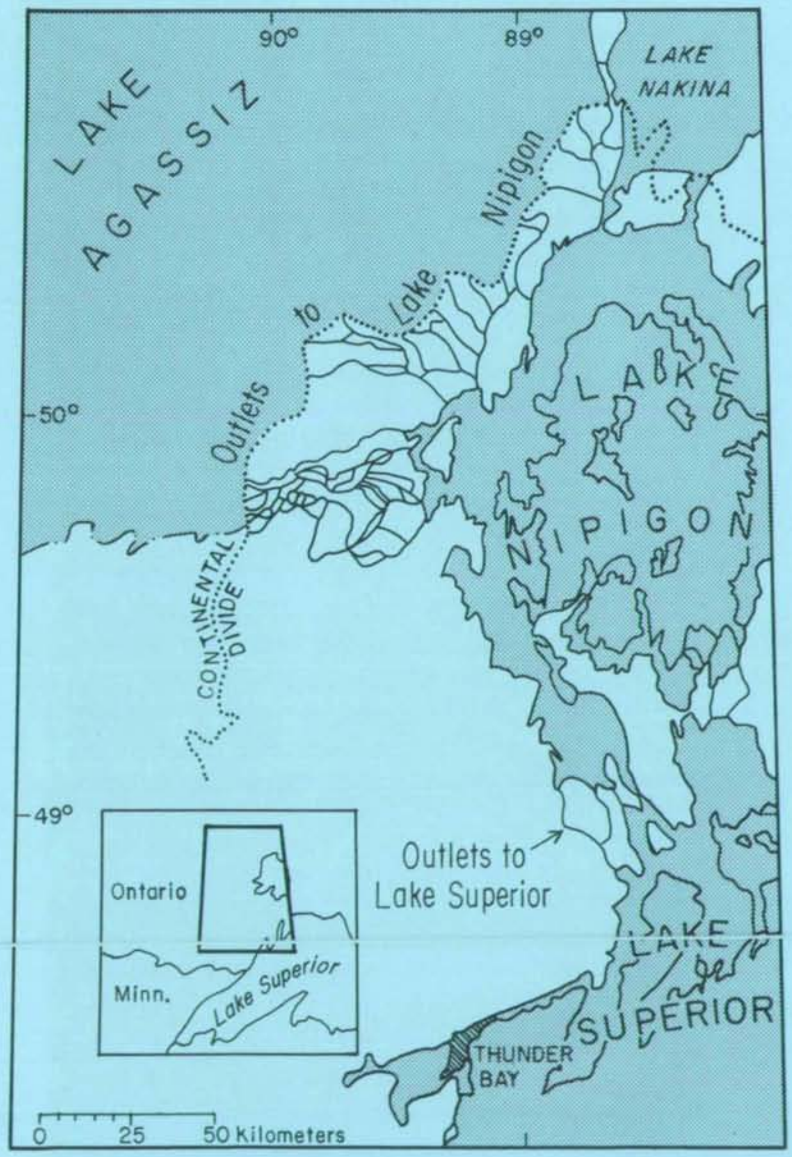


FIGURE 12.

Gorges cut by the eastern outlet of Glacial Lake Agassiz to Lake Nipigon and thus to Lake Superior when the ice sheet retreated into Canada. This first occurred about 11,000 years ago and caused the southern outlet (River Warren) to be abandoned. Readvance of the ice about 10,000 years ago closed the gorges and temporarily restored the southern outlet. Final retreat reactivated some of the Ontario gorges. The extent of glacial lakes is shown in gray. Modified from Teller and Thorleifson (1983).

conspicuous strandline or beach deposit at that level. But as the ice retreated and the lake enlarged, the greater volume of water passing through the outlet breached the pavement and eroded the gorge to a greater depth, again forming a pavement and leaving the earlier pavement as a terrace along the sides of the gorge. Again the lake level was stabilized, and a second strandline was formed. Altogether four levels formed this way.

River Warren was initiated about 11,700 years ago, according to a radiocarbon date on the earliest Lake Agassiz strandline. The southern outlet was temporarily abandoned about 11,000 years ago, when the ice lobe retreated far enough into northwestern Ontario to permit drainage eastward through a whole series of now-dry gorges (Fig. 12) into Lake Nipigon and thus Lake Superior, the other Great Lakes, and the North Atlantic Ocean (Teller and Thorleifson, 1983). By this time Lake Agassiz covered much of southern Manitoba and Saskatchewan (Fig. 13). Readvance of the ice restored the River Warren outlet about

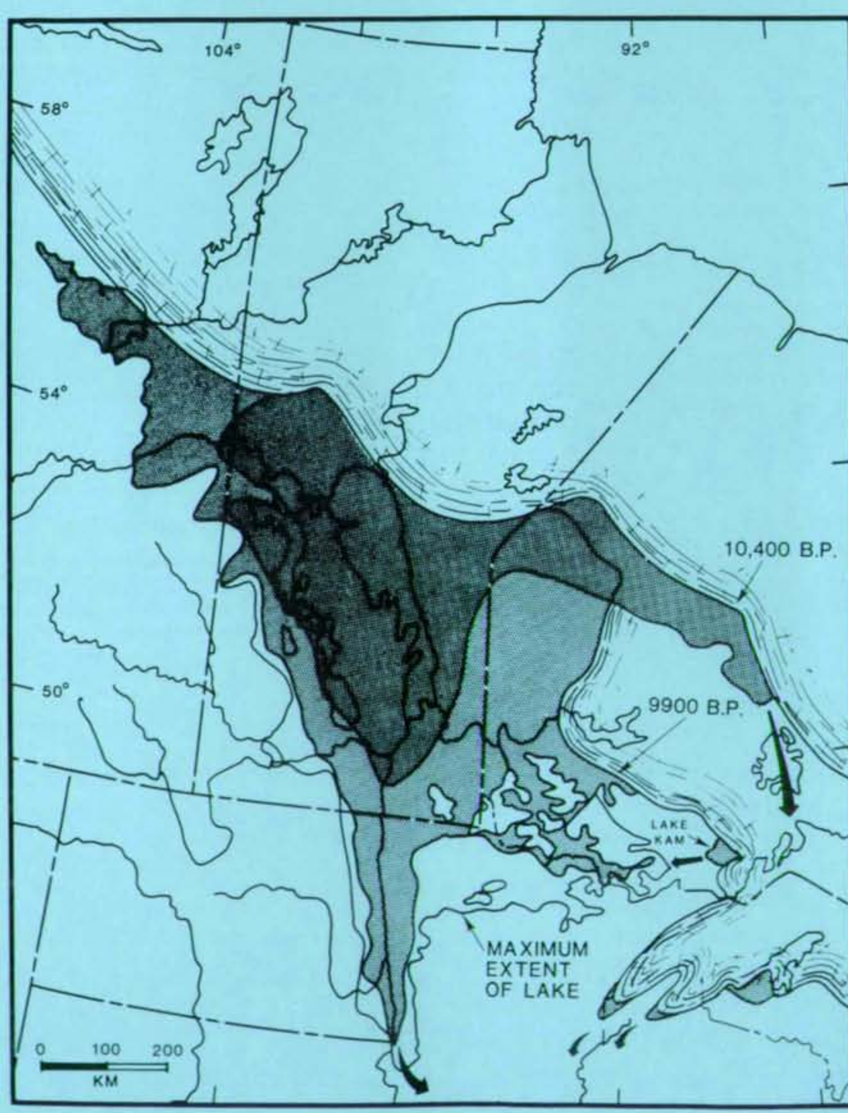


FIGURE 13.

Glacial Lake Agassiz at its maximum extent (thin line), with a southern outlet; a later stage about 10,400 years ago (dark gray), with a eastern outlet into Lake Nipigon (see also Fig. 12); and a still later stage about 9900 years ago (light gray), with the southern outlet restored and with temporary inflow from a small proglacial lake (Lake Kaministikwia), which carried red clays from the Superior lobe into Lake Agassiz. Modified from Teller (1987); reprinted by permission of the Geological Society of America.

10,000 years ago, but final diversion again to Lake Nipigon came about 9,500 years ago, and River Warren ended.

Downstream, River Warren in the Minneapolis–St. Paul area was initially superimposed on the resistant limestone of the Platteville Formation beneath the easily eroded glacial sediments. At the point in downtown St. Paul where the River Warren reentered a buried river channel a waterfall developed (Fig. 4). It retreated upstream by easily undercutting the poorly cemented St. Peter Sandstone beneath the caprock. The River Warren waterfall must have been about sixty meters high as it moved upstream ten kilometers to Fort Snelling. Upstream from Fort Snelling the River Warren waterfall continued southwestward another few kilometers, where it became extinguished as the river course crossed the buried valley that extends south from the Lake Calhoun area in western Minneapolis.

But as the retreating waterfall passed the entrance of the Mississippi River at Fort Snelling, a tributary waterfall was initiated as the incipient St. Anthony Falls (Fig. 14). About three kilometers upstream from Fort Snelling, the Mississippi River was split into two channels, forming an island, and the waterfall proceeded up each arm. Minnehaha Creek entered the western arm, and a tributary waterfall started up that course. Meanwhile the waterfall on the eastern arm—the present course of the Mississippi River—was larger and retreated more rapidly, thereby beheading the western arm and leaving the dry waterfall visible from Minnehaha Parkway at the head of Minnehaha Park. St. Anthony Falls continued to retreat upstream and split once again to form Hennepin Island. There it provided the power source for the mills that initially served as the economic base for the city of Minneapolis. Further retreat of the falls has

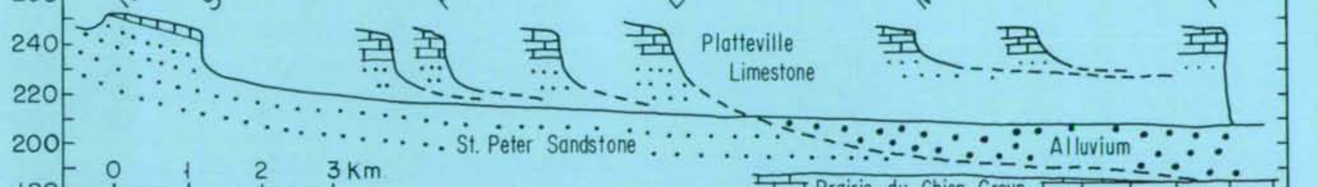


FIGURE 14.

Progress in the retreat of St. Anthony Falls from Fort Snelling to its present position near downtown Minneapolis. The rate of retreat probably accelerated as the thickness of the limestone caprock decreased toward the northern margin of the structural bedrock basin. If the retreat had continued for another few centuries, the falls would have intersected a buried bedrock valley and thus ended its existence. Redrawn from Sardeson (1916).

been prevented by protective structures, and the eastern branch is the site for the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota.

The location of St. Anthony Falls was first recorded by Father Louis Hennepin during his explorations in 1680 and later by other explorers (Fig. 15). Newton Horace Winchell, the first director of the Geological and Natural History Survey of Minnesota, compiled records of the retreat in 1888 and calculated a rate of retreat during the preceding 200 years. He then extrapolated this rate over the thirteen kilometers to Fort Snelling, yielding a date of about 8,000 years as the minimum age for the Glacial River Warren and thus for Glacial Lake Agassiz and the last glaciation. This estimate is remarkably close to the radiocarbon dates for these events. Winchell's estimate was one of the first reliable figures for geologic time, and it was especially significant in the context of the contemporaneous debates about Darwinian evolution and related phenomena that involved the dimensions of geologic time.

Downstream from St. Paul, the dissection of the River Warren gorge also proceeded in steps, leaving terraces in places, although correlation of these terraces with the Lake Agassiz strandlines is not yet possible. In the Mississippi River valley between St. Paul and Hastings, for example, several terraces are conspicuous on and near Grey Cloud Island. Another phenomenon during the dissection was the splitting of the river into two or more channels. Thus

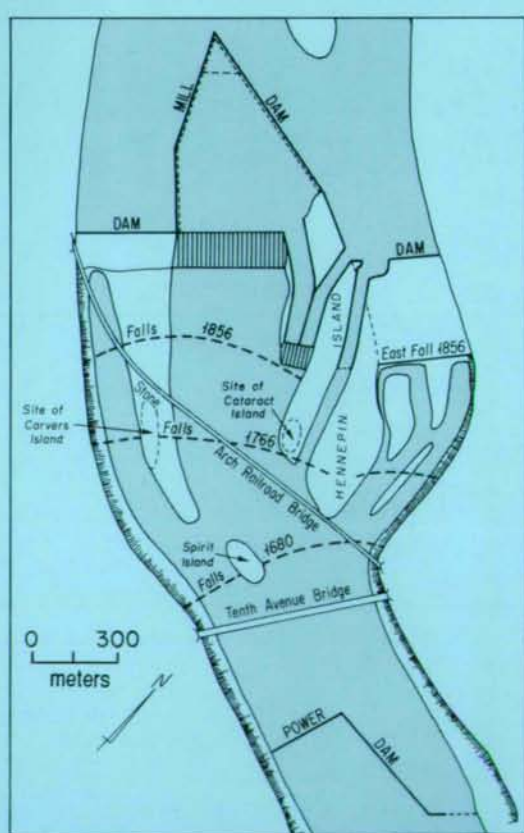


FIGURE 15.

Positions of St. Anthony Falls as sketched in 1680 and later. Newton Horace Winchell extrapolated the rate of retreat to estimate the length of postglacial time From Winchell and Upham (1888); redrawn from Sardeson (1916).

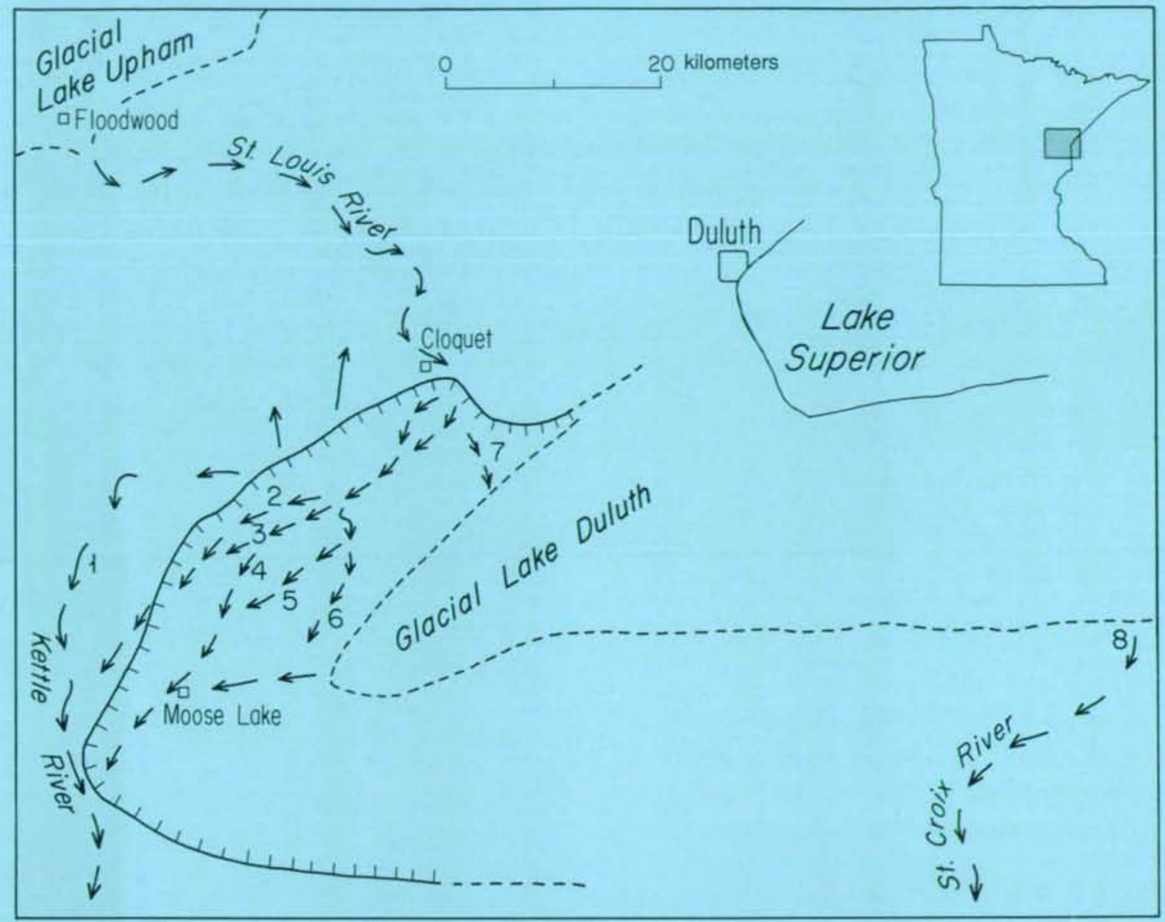


FIGURE 16.

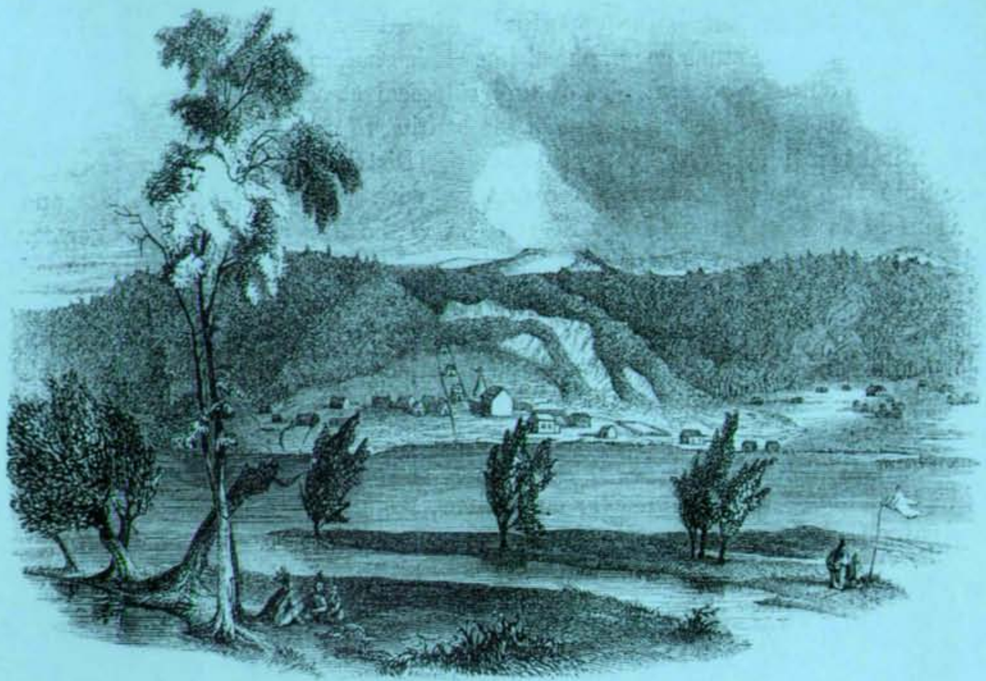
Successive diversion channels (numbered) of the St. Louis River as it cut into the retreating Superior lobe (hachured line) or the moraines left by the ice. These channels drained into the Kettle River and thence into the St. Croix River. With further ice retreat, Glacial Lake Duluth was enlarged and drained by the Brule River in Wisconsin, the headwater tributary of the St. Croix River. Modified from Wright and Watts (1969).

the river split around the bluffs near Frontenac and eroded both courses until the eastern branch beheaded the western, which was left as the trough now occupied by the railroad and highway (Fig. 10). Similarly, far upstream the River Warren split into different channels near Lac Qui Parle. Watson Sag was left behind when the more westward channel cut more deeply.

The total depth cut by River Warren below the glacial outwash terrace south of St. Paul was about sixty-five meters.

St. Croix River

THE GORGE OF THE ST. CROIX RIVER had been deepened by the outflow from Glacial Lake Duluth (a predecessor of Lake Superior). The spectacular potholes at Taylors Falls were formed by the turbulent water flow at this time. Prior to the formation of Glacial Lake Duluth, the St. Croix River received the drainage from Glacial Lake Upham to the west and the St. Louis River, which was diverted by the Superior lobe to flow southward to



FOND DU LAC VILLAGE, ST. LOUIS RIVER.

the Kettle River and thus to the St. Croix River (Fig. 16). As this ice retreated, the St. Louis River eroded successively lower channels in the moraines left by the ice. The river eventually broke through the moraines to Lake Duluth, which initially drained into the Kettle River and, subsequently, to the headwaters of the St. Croix River (the modern Brule River) in Wisconsin. When the ice left the Lake Superior basin, Glacial Lake Duluth was further lowered as its modern drainage to the east was gained.

POSTGLACIAL RIVERS

WHEN THE OUTLET OF LAKE AGASSIZ was diverted to the northeast, the successor to River Warren—namely, the Minnesota/Mississippi River—no longer had adequate discharge to erode its bed, or even to transport all the sediment entering from tributaries. Thus the Chippewa River of Wisconsin, carrying sandy sediment from southwestern Wisconsin, deposited a fan across the Mississippi River near Wabasha and created Lake Pepin (Fig. 17). In a similar way far upstream near the border with South Dakota, the Minnesota River was dammed by the Lac Qui Parle River from the west and the Chippewa River of Minnesota from the east near Watson to form Lac Qui Parle. It was also dammed by a fan of the Whetstone River from the west at Ortonville on the South Dakota border to form Big Stone Lake. The fan of the Little Minnesota River from the west at Browns Valley not only formed Lake Traverse but reversed the drainage of the River Warren gorge, so that Lake Traverse forms the head of the Red River of the North (Fig. 11).

Lake Pepin originally extended upsteam to St. Paul and was thus about one hundred kilometers long, or two-and-a-half times its present length (Zumberge 1952). A

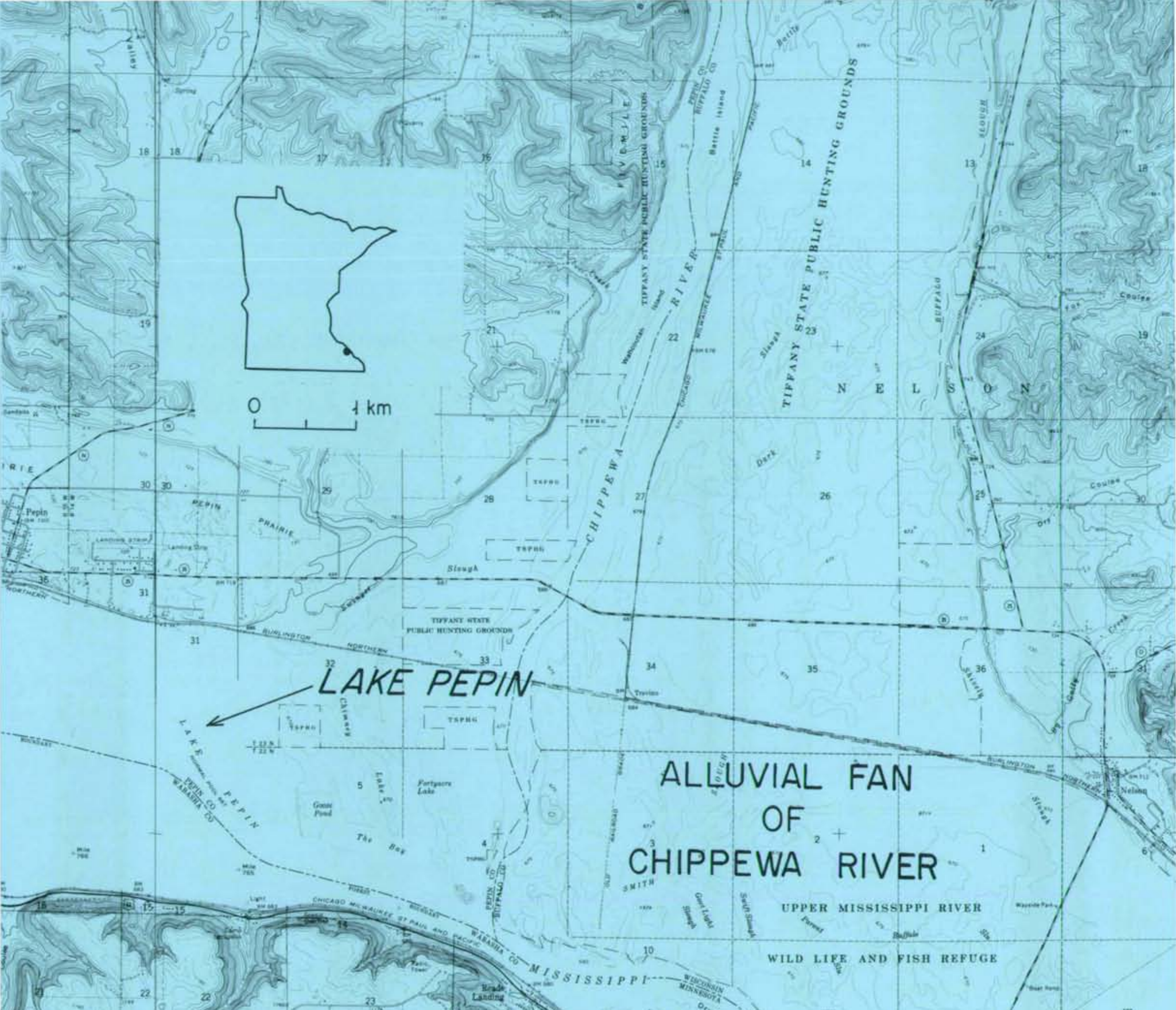


FIGURE 17.

Alluvial fan of the Chippewa River of Wisconsin, which dammed Lake Pepin when the large discharges of the Glacial River Warren ceased. Reduction from U.S. Geological Survey 7.5-minute topographic maps of the Wabasha North and Pepin quadrangles (1974).

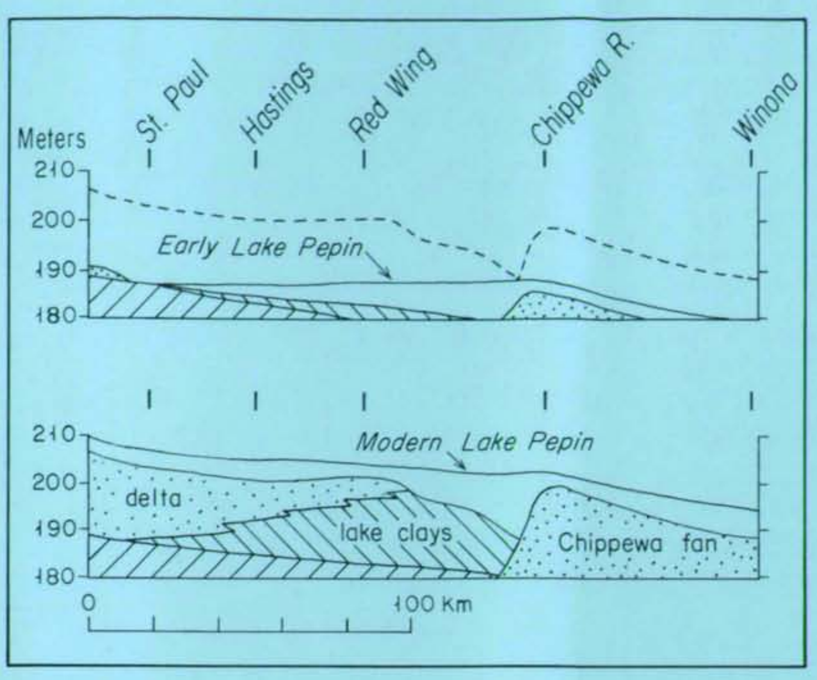


FIGURE 18.

Longitudinal section of the Mississippi River valley from Lake Pepin upstream to St. Paul, showing the progressive advance of the delta and the filling of the lake, which originally extended to St. Paul. The dashed line on the top diagram represents the modern river-bottom profile. Modified from Zumberge (1952).

delta formed where the Mississippi River entered Lake Pepin and has since advanced to fill in the head of the lake (Fig. 18). As the delta progressed downstream it dammed the mouth of the St. Croix River, thus forming Lake St. Croix, which is similarly being filled in at its head by a delta at Stillwater.

RIVER HISTORY AND FUTURE

ALTHOUGH TODAY MINNESOTA is at the headwaters of three continental drainage systems—the Minnesota and Mississippi Rivers to the Gulf of Mexico, the Red River of the North to Hudson Bay, and the St. Louis River to Lake Superior and the North Atlantic Ocean, all of these river systems were connected at different times late in the glacial period. Thus the Red River area was connected to the Mississippi River by way of Lake Agassiz and the River Warren. Later it was joined to Lake Superior and the North Atlantic Ocean by the Lake Nipigon outlets of Lake Agassiz. The St. Louis River/Lake Superior area was connected to the Mississippi by way of Glacial Lake Duluth and the St. Croix River.

One can imagine the Minnesota River Valley at Fort Snelling as being filled year-round wall-to-wall with the River Warren—and a waterfall sixty meters high. Or picture the spectacular boulder-floored gorges that once took the Lake Agassiz outlet waters to Lake Nipigon. We may acknowledge the modern Lake Superior to be supreme in its size and depth, but Glacial Lake Duluth was one hundred and forty meters deeper, and Glacial Lake Agassiz at its maximum was larger than all the modern Great Lakes combined.

Physically the modern river scene is relatively quiet compared to that of glacial times, although changes of a

DESCRIPTION OF THE COUNTRY

DALLES OF KETTLE RIVER

different kind threaten—siltation, pollution, and reduction in river wetlands. Vigorous programs to decrease the degradation provide the opportunity to restore the major rivers at least part way to their condition a century ago. The recent designation of the Mississippi River in the Minneapolis–St. Paul area as a national scenic river and recreation area should lead to some improvement in water quality. But the structures installed for commercial transport, flood control, and hydroelectric power have altered the natural characteristics of the river for the indefinite future. The historical perspective attempted here may provide further incentives for protection and restoration of the other major river segments.

REFERENCES CITED

Bray, E.C., 1985, Ancient valleys, modern rivers: What the glaciers did: St. Paul, Science Museum of Minnesota, 32 p.

Cooper, W.S., 1935, The history of the upper Mississippi River in late Wisconsin and postglacial time: Minnesota Geological Survey Bulletin 26, 116 p.

Olsen, B.M., and Mossler, J.H., 1982, Geologic map of Minnesota, bedrock topography: Minnesota Geological Survey State Map Series S-15, scale 1:1,000,000.

Sardeson, F.W., 1916, Minneapolis–St. Paul folio, Minnnesota, *part of the* Geologic atlas of the United States: U.S. Geological Survey Geologic Folio 201, 14 p., maps.

Schneider, A.F., 1961, Pleistocene geology of the Randall region, central Minnesota: Minnesota Geological Survey Bulletin 40, 151 p.

Teller, J.T., 1987, Proglacial lakes and the southern margin of the Laurentide Ice Sheet, *in* Ruddiman, W.F., and Wright, H.E., Jr., eds., North America and adjacent oceans during the last deglaciation: Geological Society of America, The Geology of North America, v. K-3, p. 39–69.

Teller, J.T., and Thorleifson, L.H., 1983, The Lake Agassiz–Lake Superior connection, *in* Teller, T.J.,and Clayton, L., eds., Glacial Lake Agassiz: Geological Association of Canada Special Paper 26, p. 261–290.

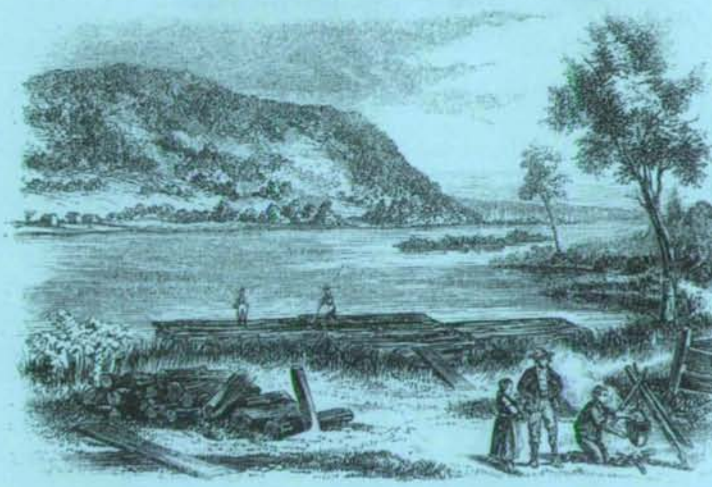
Winchell, N.H., and Upham, W., 1888, The geology of Minnesota; vol. II of the final report: Minnesota Geological and Natural History Survey, 695 p.

Wright, H.E., Jr., 1972, Quaternary history of Minnesota, *in* Sims, P.K., and Morey, G.B., eds., Geology of Minnesota: A centennial volume: Minnesota Geological Survey, p. 515–547.

——— 1973, Tunnel valleys, glacial surges, and subglacial hydrology of the Superior lobe, Minnesota: Geological Society of America Memoir 136, p. 251–276.

Wright, H.E., Jr., and Watts, W.A., 1969, Glacial and vegetational history of northeastern Minnesota: Minnesota Geological Survey Special Publication Series SP-11, 59 p.

Zumberge, J.H., 1952, The lakes of Minnesota: Their origin and classification: Minnesota Geological Survey Bulletin 35, 99 p.



OUTLET OF LAKE PEPIN.