PLEISTOCENE GEOLOGY and EVOLUTION of the UPPER MISSISSIPPI VALLEY

a working conference

PROGRAM ABSTRACTS FIELD GUIDE

August 13-16, 1985
on the campus of
Winona State University
Winona, Minnesota

Sponsored by: The Minnesota Geological Survey and the Department of Professional Development and Conference Services, Continuing Education and Extension, University of Minnesota
<table>
<thead>
<tr>
<th>Time</th>
<th>Talk Title</th>
<th>Author(s)</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>0800</td>
<td>GEOLOGIC HISTORY OF VALLEY INCISION IN THE DRIFTLESS AREA</td>
<td>James C. Knox</td>
<td>5</td>
</tr>
<tr>
<td>0835</td>
<td>PREGLACIAL DRAINAGE IN THE UPPER MISSISSIPPI VALLEY REGION</td>
<td>Richard C. Anderson</td>
<td>9</td>
</tr>
<tr>
<td>0910</td>
<td>DIVERSION OF PREGLACIAL RIVERS BY THE ICE AGE</td>
<td>Edmund C. Bray</td>
<td>10</td>
</tr>
<tr>
<td>0945</td>
<td>QUATERNARY HISTORY OF SOUTHEASTERN MINNESOTA</td>
<td>Howard C. Hobbs</td>
<td>11</td>
</tr>
<tr>
<td>1110</td>
<td>CONTRASTING AGE OF THE MISSISSIPPI RIVER VALLEY IN EAST-CENTRAL MINNESOTA AND ITS TRIBUTARIES IN WEST-CENTRAL WISCONSIN</td>
<td>Robert W. Baker</td>
<td>20</td>
</tr>
<tr>
<td>1300</td>
<td>THE BEDROCK GEOLOGY OF SOUTHERN MINNESOTA AND ITS RELATIONSHIP TO THE HISTORY OF THE MISSISSIPPI RIVER VALLEY</td>
<td>Bruce M. Olsen</td>
<td>21</td>
</tr>
<tr>
<td>1335</td>
<td>INFLUENCE OF STRUCTURE AND ROCK TYPE ON THE FORMATION OF BEDROCK VALLEYS IN THE TWIN CITIES AREA, MINNESOTA</td>
<td>Mark A. Jirsa</td>
<td>25</td>
</tr>
<tr>
<td>1410</td>
<td>PLEISTOCENE FLUVIAL GEOMORPHOLOGY OF SOUTHEASTERN MINNESOTA</td>
<td>Robert E. Sloan</td>
<td>27</td>
</tr>
<tr>
<td>1530</td>
<td>FIELD TRIP TO STOPS 1 AND 2</td>
<td></td>
<td>69-78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0800</td>
<td>KARST AND THE PLEISTOCENE HISTORY OF THE UPPER MISSISSIPPI RIVER VALLEY</td>
<td>R.S. Lively and E.C. Alexander, Jr.</td>
<td>31</td>
</tr>
</tbody>
</table>
0835 OVERVIEW OF LANDSCAPE EVOLUTION IN NORTHEASTERN IOWA, I: PRE-WISCONSINIAN--
George R. Hallberg and E. Arthur Bettis III 33

0910 OVERVIEW OF LANDSCAPE EVOLUTION IN NORTHEASTERN IOWA, II: WISCONSINIAN--
George R. Hallberg and E. Arthur Bettis III 36

0945 THE SAVANNA (ZWINGLE) TERRACE AND "RED CLAYS" IN THE
UPPER MISSISSIPPI RIVER VALLEY: STRATIGRAPHY AND CHRONOLOGY--
E. Arthur Bettis III and G.R. Hallberg 41

1035 QUATERNARY ALLUVIAL STRATIGRAPHY AND CHRONOLOGY OF ROBERTS
CREEK BASIN, NORTHEASTERN IOWA--
E. Arthur Bettis III and G.R. Hallberg 44

1110 SURFICIAL DEPOSITS ON THE PALEOZOIC SURFACE IN SOUTHEASTERN
MINNESOTA: THEIR DISTRIBUTION AND GEOMORPHIC RELATIONSHIPS--
Robert Lueth 46

1300 TILL STRATIGRAPHY AND GLACIAL HISTORY OF BARRON COUNTY,
WISCONSIN--
Mark D. Johnson 48

1335 TERMINAL PLEISTOCENE EVENTS IN THE MISSISSIPPI VALLEY NEAR
ST. LOUIS AS INFERRED FROM ILLINOIS VALLEY GEOLOGY--
Edwin R. Hajic 49

1410 THE PLEISTOCENE STRATIGRAPHY OF THE BUFFALO RIVER VALLEY,
WISCONSIN--
R.D. Dunning 53

1500 DEVELOPMENT OF THE MISSISSIPPI RIVER FROM THE LATE ILLINOIAN
THROUGH EARLY HOLOCENE AS RECORDED IN TERRACE REMNANTS ALONG
THE LOWER IOWA AND CEDAR RIVERS, SOUTHEAST IOWA--
S.P. Esling and G.R. Hallberg 55

1535 USE OF CLAY MINERALOGY AND RADIOCARBON DATING IN THE
INTERPRETATION OF SEDIMENTARY UNITS, MOUND CITY, ILLINOIS--
Philip C. Reed, John M. Masters, and Herbert D. Glass 58

1700 RIVERBOAT CRUISE ON THE WINONA PRINCESS

1915 CASH BAR AND DINNER ON THE JULIUS C. WILKIE STEAMBOAT

2000 ENVIRONMENTAL GEOLOGY OF THE UPPER MISSISSIPPI RIVER SINCE
1800--
Dennis N. Nielsen, Dinner Speaker 59

REFERENCES CITED-- 61
0730 FIELD TRIP
Howard C. Hobbs, R.S. Lively, and Bruce M. Olsen

STOP 1. THE ANDERSON-QUAVERY QUARRY [seen August 13] 69
STOP 2. THE WINONA COUNTY LANDFILL [seen August 13] 73
STOP 3. STEIGER NORTH QUARRY, NORTHWEST OF ALTURA 79
STOP 4. SANDPIT SOUTH OF ELBA 82
STOP 5. "ST. CHARLES" TILL EXPOSURE SOUTH OF UTICA 84
STOP 6. CEMENTED GRAVEL NEAR CLYDE 87
STOP 7. RUSH CREEK VALLEY 90
STOP 8. MYSTERY CAVE, SOUTH BRANCH OF THE ROOT RIVER AND ENVIRONS 94
STOP 9. ALLUVIAL TERRACE NEAR RUSHFORD 99
STOP 10. ROAD CUT SOUTH OF HOKAH ALONG HOUSTON COUNTY ROAD 18 102

August 16, 1985

0830 HALF-DAY WRAP-UP SESSION
Little can be said definitively about the pre-Wisconsinan history of the Mississippi River valley between St. Paul and Iowa. The most useful review of possible early events is to be found in Martin (1965). The valley must be younger than the Cretaceous near-shore marine deposits that are found on the upland of southeastern Minnesota, but Martin is uncertain when the valley was established and why it is located where it is—whether the valley is antecedent to whatever post-Cretaceous deformation there was, or whether it was superposed from a Cretaceous (or Tertiary?) sedimentary cover.

At some time in the early Pleistocene the gorge was first cut, as indicated by the presence of till generally correlated with the Kansan Glaciation. The gray color and strongly calcareous nature of the deposits indicate that the ice came from the northwest and terminated at the western edge of the slightly higher terrain that is the Driftless Area of southwestern Wisconsin. Recent investigations by Baker and others (1983) indicate that the ice depositing this till blocked the streams draining westward from Wisconsin, and paleomagnetic results indicate that the glaciolacustrine deposits in the lakes thereby formed are older than 700,000 years—consistent with a Kansan (or at least pre-Illinoian) age.

Although this old till occupies the inner valley, there is no evidence that the gorge was eroded by the ice sheet. Rather, the gorge was probably cut by the river itself prior to the first recorded glaciation. Its alternating narrow and broad stretches reflect the structure of the gently dipping Paleozoic rocks into which it is cut: narrow sections occur where the resistant carbonate formations dip down to river level, and broad sections occur where the resistant beds form the higher bluffs that have migrated back as the softer sandstones beneath have been eroded.

The old till of western source is overlain in western Wisconsin northwest of the Driftless Area (and across the river in Dakota County, Minnesota) by red till deposited by an ice lobe from the Lake Superior basin. Paleomagnetic measurements suggest an age younger than 700,000 years, and the deep paleosol on the surface of the drift indicates that the ice advance represented should be correlated with the Illinoian Glaciation (Baker and others, 1983).

During the Wisconsinan Glaciation the previously existing gorge became partially filled with outwash, first from the Superior lobe when it terminated at the St. Croix moraine near St. Paul and Dakota County, and then from the Des Moines lobe and Grantsburg lobe (Wright, 1972). The outwash deposits blocked the drainage of Mississippi River tributaries, causing small lakes or at least valley flats to form. The backflooding up these tributaries was sufficient in cases to allow low passes to be topped, making islands out of portions of the upland. The Mississippi River itself
temporarily occupied some of these passes, such as west of the Trempealeau Bluffs near Frontenac.

As the last ice lobe retreated, the Mississippi River commenced to dissect its outwash, leaving terraces behind. The pace of dissection undoubtedly accelerated when the Des Moines lobe retreated into Canada and left in its wake Glacial Lake Agassiz, whose outlet stream (Glacial River Warren) had a tremendous flow of water with little sediment to transport. Between Minneapolis and St. Paul the riverbed was on resistant Paleozoic carbonate rocks, but below St. Paul the river rapidly re-excavated the glacial filling of the old gorge. A waterfall formed at the point where the river left the carbonate caprock, and retreated by undercutting of the soft St. Peter Sandstone. After about 20 km of retreat, the gorge had extended beyond the localized Platteville caprock, and deep dissection proceeded. Ultimately the gorge was eroded to a depth of perhaps 50 m below the present floodplain, as indicated by borings (Zumberge, 1952).

When the ice had retreated far enough into Canada to allow Glacial Lake Agassiz to drain to the north, about 9200 years ago, Glacial River Warren was beheaded, and its successor (the Minnesota/Mississippi River) no longer had the large water volume necessary to provide the river velocity required to transport the sediment supplied by tributary streams. Deposition on the floodplain then ensued, especially at the mouths of tributaries. At the mouth of the Chippewa River on the Wisconsin side, the sandy alluvium formed a fan across the Mississippi, creating Lake Pepin, which originally extended about 80 km farther upstream to St. Paul, as indicated by the presence of lake sediments at the base of borings through delta alluvium. Lake Pepin is destined to be filled as the delta continues to prograde into the head of the lake, and the river will continue to aggrade until some kind of steady state is reached between supply of water and sediment and the gradient of the river.

An interesting side effect of this delta progradation is the sandbar formed by accumulation of Mississippi River sediment across the mouth of the St. Croix River, creating Lake St. Croix in its lower 50 km.
Karst processes have had a profound, but subtle, influence on the geomorphology of the Upper Mississippi River valley. During the deposition of the Paleozoic sedimentary rocks which underlie the region, there were several episodes of subaerial karst formation that form the unconformities between many of the Paleozoic formations.

The Upper Mississippi River valley has been above water and eroding throughout the Tertiary and probably a significant part of the Cretaceous. As the near-surface bedrock consists predominantly of carbonate rocks, karst processes have had 50 to 100 million years to operate on the land surface. During much of this interval, the area was one of subdued relief with drainage toward the epicontinental seas to the west. Low gradients, both of surface streams and ground water, resulted in a slow but pervasive karst weathering.

The Pleistocene glacial cycles have profoundly influenced the karst activity of the Upper Mississippi valley. During the cold parts of the glacial cycles, the permafrost and ice cover lower production of CO₂ in the soil, slow subsurface flow and reduce the H₂CO₃ loading of water moving in the subsurface. One class of glacial processes that slows the karst development is the burial of the carbonate bedrock by glacial drift/outwash and loess deposits. In regions where thick deposits of drift and/or outwash blanket the surface, karst processes are essentially halted (but not reversed—the pre-existing karst features remain, they are just buried). Loess deposits tend to mantle karst features and slow karst processes. The loess may contain a significant carbonate component which, until it is leached away, neutralizes much of the carbonate dissolving capacity of the meteoric water infiltrating through the soil.

In contrast to glaciation, the establishment and incision of the Mississippi drainage system has served to lower the regional base level, increase the available hydraulic gradients, and speed up karst processes during the warm periods of the glacial cycles in those regions not covered by deep glacial deposits.

It is therefore not surprising that what Derek Ford has referred to as "glacially deranged karsts" are complicated and often not very obvious. Sinkholes, the classic, characteristic surface feature of karsts, are often too small and/or too transient to be recorded even on the 7-1/2-minute topographic sheets. Janet Dalgleish (Dalgleish and Alexander, 1984) has recently shown that only about 15 percent of the sinkholes in Winona County are shown on topographic sheets or other existing maps.

Much of the carbonate uplands of the Upper Mississippi River valley is partially to wholly drained through the subsurface. The resulting dry valleys, blind valleys, caves, and resurgent springs form major parts of the near-surface ground-water system. The subsurface drainage becomes an
important factor in the erosion process. Sheila Grow (Grow and Alexander, 1985) has recently demonstrated that the dissolution of limestone and dolomite by the ground water in an area of Fillmore County corresponds to a surface lowering of about 5 cm per 1,000 years when averaged across the entire drainage basin. This dissolution is not, however, uniform across the surface, but is more concentrated in some regions than in others. Although this rate presumably applies only during interglacial times, if interglacial conditions prevailed during 10 percent of the Pleistocene, karst solution could have lowered the regional land surface about 10 m (30 ft).

As is characteristic of karsts everywhere, the surface of the bedrock normally has much more topography on it than does the actual land surface. This topography consists of filled sinkholes, enlarged joints, cutters, etc. This phenomenon is very evident in quarries which expose the bedrock/soil interface and is easily visible in the walls of the Anderson-Quavery Quarry (Stop 1).

From a scientific point of view, one of the most interesting aspects of the Upper Mississippi valley karst is that the caves and solution-enlarged joints in the carbonate rocks can preserve a record of the area's geologic history from subsequent surface erosion. This record is observed primarily in the sediments washed into the cavities and in the speleothems forming therein. Such sediments and speleothems are already providing the first chronologic control on the pre-Wisconsinan glacial history of the Upper Mississippi valley.
The hilly, stream dissected, unglaciated topography of southwestern Wisconsin (Driftless Area) once was viewed as representative of what much of the Upper Mississippi valley landscape might have looked like before modification by Pleistocene glacial events. While it is now generally accepted that the deep dissection of the Wisconsin Driftless Area, as well as topographically similar, but glaciated areas in adjacent states, occurred within the Pleistocene, the precise chronology has remained poorly understood. This paper presents information that correlates specific topographic features of the Driftless Area with glacial deposits on the margins of the Driftless Area. The correlations form a basis for inferring a geologic history of valley incision in the Driftless Area.

The history of drainage entrenchment in the Upper Mississippi valley has been debated for many years. Early investigators, such as Chamberlin and Salisbury (1885), McGee (1891), Leverett (1921), Trowbridge and Shaw (1916), Alden (1918), and Horberg (1945) assumed that the major valleys were entrenched in preglacial time because they believed the Pleistocene was too short to account for the magnitude of valley cutting. Hershey (1896) appears to have been one of the first to question the pre-Pleistocene age assignment for deep incision of the valleys, but more conclusive evidence against pre-Pleistocene entrenchment of the drainage was presented in a series of publications by Trowbridge (1921, 1935, 1954, 1959, and 1966). Willman and Frye (1969, 1970) reviewed the literature on valley entrenchment and presented new evidence indicating that the deep incision and positioning of the Mississippi River along the western margin of the Driftless Area has occurred since early Pleistocene, or "Nebraskan time" in the classical stage name terminology.

The relative topographic relationships of Pleistocene sediments to ancient erosion surfaces and entrenched valleys are usually used as evidence for Pleistocene incision of valleys. The upland landscape of the Driftless Area suggests evidence of two relict Tertiary erosion surfaces that were assigned the names "Dodgeville" and "Lancaster" by Trowbridge (1921). The Dodgeville surface is restricted to small areas on the higher interfluves of the main drainage divides in the region, whereas the Lancaster surface typically occurs about 30-50 m lower in elevation on the interfluves of the tributary drainage divides. While many interpretations have been suggested for the origins of the relict erosion surfaces (Thwaites, 1960), some argue that the pre-Pleistocene relief of the Driftless Area is approximated by the range of elevations represented on these two erosion surfaces. Trowbridge (1954, 1966), for example, reported that pre-Illinoian glacial till in northeastern Iowa lies at and above the level of the Lancaster surface and in sinks and caves less than about 30-35 m below that level, but that no pre-Illinoian till occurs on valley bottoms, terraces, or slopes of the valleys. Trowbridge believed that the present course of the Upper Mississippi River along the western margin of the Driftless Area was established in "classical Nebraskan" time when
Nebraskan glacial ice displaced the Mississippi River eastward from a NW-SE course through central Iowa to its present position. Willman and Frye (1969, 1970) accepted Trowbridge's conclusion and further postulated that the rivers of the Driftless Area north of the Silurian Escarpment in northwestern Illinois drained northward prior to displacement of the Mississippi River by Nebraskan ice. Willman and Frye (1969, 1970) interpreted high-level gravel deposits on uplands adjacent to the Mississippi River in the Driftless Area of northwestern Illinois as indicating that the Mississippi River was not in its present position when the gravels were deposited. They speculated that well-bedded silt and clay underlying the high-level gravels might represent lacustrine sediments that accumulated in a lake trapped between the east margin of the Nebraskan ice, the Wisconsin uplands, and the Silurian Escarpment in northwestern Illinois. They suggested that the lake would eventually have over-topped a low sag in the Silurian Escarpment, and the drainage then rapidly entrenched into the underlying bedrock. Willman and Frye (1969) stated that the presence of Kansan outwash, generally overlain by Kansan till, in the deepest parts of major buried valleys throughout central Illinois is evidence that the Mississippi River was deeply entrenched before the Kansan maximum.

Stratigraphic evidence from within the Wisconsin Driftless Area also supports the interpretation that entrenchment of the drainage below the level of the Lancaster erosion surface occurred during the Pleistocene (Knox, 1982; Knox and others, 1982). A key indicator of the erosional history is the occurrence of pre-Illinoian till on the Bridgeport strath in the lower Wisconsin River valley near its junction with the Mississippi River. The clay mineralogy of the Bridgeport till is very similar to the clay mineralogy of till units in the pre-Illinoian Wolf Creek Formation of eastern Iowa (Hallberg, 1980a) and the pre-Illinoian Hersey till of the Pierce Formation in west-central Wisconsin on the northwestern margin of the Driftless Area (Baker, 1984). In classical stage name terminology, these till units probably would be assigned to the Kansan stage of glaciation. Trowbridge (1954, p. 803) suggested that the strath surface underlying the Bridgeport till represented "...the depth to which the Mississippi and Wisconsin Rivers had cut their valleys by the time the Kansan glacier reached this position." Trowbridge's conclusion is only partially correct because outwash from the Bridgeport till extends below the strath surface, suggesting that valleys had been trenched well below the elevation of the strath when the Bridgeport till was deposited.

Outwash deposits of pre-Illinoian age occur commonly on upland divides adjacent to the Mississippi River along the western margin of the Driftless Area in Wisconsin. These deposits usually are restricted to within a few kilometers of the Mississippi River trench. However, in at least one instance the outwash spilled over a drainage divide at an elevation of about 300 m above sea level (120 m above the present floodplain of the Mississippi River) and drained into the south-flowing Grant River drainage of western Grant County, Wisconsin. Only small quantities of the outwash remain, such as quartz and mafic igneous small pebbles, granules, and finer sediments. Their distribution is restricted to valley-side benches extending as low as 10 to 20 m above modern floodplain levels. No outwash was found on the highest parts of the landscape represented by the Dodgeville and Lancaster erosion surfaces except in locations immediately
adjacent to the Mississippi River. The age of the outwash sediments cannot
be precisely determined, although the assemblage of erratics is very simi­
lar to those associated with the Bridgeport till. Unfortunately the
mineral assemblages of pre-Illinoian tills of northeastern Iowa are not
greatly different from each other, causing difficulty in differentiating
tills (Trowbridge, 1966). The outwash in the Grant River implies that a
drainage outlet was open to the south when it was deposited, because the
Grant River drains southward into the Mississippi River. If these sedi­
ments correlate with the classical Nebraskan drift deposits of Trowbridge
(1966) and Willman and Frye (1969), then it seems unlikely that drainage
was ponded behind the Silurian Escarpment of northwestern Illinois as
postulated by Willman and Frye (1969). Furthermore, lack of support for
assignment of the outwash to classical Nebraskan time is indicated by the
fact that the outwash occurs at a relatively low elevation in the Grant
River drainage, implying that the landscape had already experienced at
least 50 to 60 m of dissection at the time of outwash deposition and that
only 15 to 20 m of additional dissection has occurred since then. It seems
more likely that the age of the outwash is pre-Illinoian and corresponds
with the classical Kansan drift of Trowbridge (1966) and the Bridgeport
till on the strath at the mouth of the Wisconsin River valley. This
interpretation favors major dissection of the Driftless Area during
earliest Pleistocene time.

Cutoff valley meanders and relict valley meander scars are common
throughout the Driftless Area. These landforms preserve the elevations of
former longitudinal profiles of rivers and therefore denote former local
base levels of the drainage systems. There are at least two prominent sets
of valley meander scars in the Driftless Area. The older of the two
appears to be graded to the elevation of the strath underlying the Bridge­
port till at the mouth of the Wisconsin River (Knox, 1982), suggesting that
the scars relate to a river system that is considerably older than the
classical Kansan of Trowbridge (1954, 1966), and is very likely of
pre-Pleistocene age. It is certainly older than classical Kansan because
outwash from the Bridgeport till extends well below the strath surface in
the Wisconsin River valley. These older relict longitudinal river profiles
typically occur about 50-55 m above the bedrock floors of adjacent valleys
and 30-40 m above the floodplains of modern rivers.

The formation of cutoff valley meanders occurred episodically during the
Pleistocene when the Mississippi and Wisconsin River drainages were blocked
by glacial debris and produced massive alluviation in the lower reaches of
Driftless Area river systems. The times and frequencies of occurrence of
this phenomenon are not precisely known, but it probably happened each time
pre-Illinoian glacial ice from the west and northwest reached the Missis­
sippi River along the western margin of the Driftless Area. It undoubtedly
also happened when Illinoian glacial ice advanced westward from Illinois
into southeastern Iowa. The prominent cutoff valley meanders in the
Kickapoo valley of the central Driftless Area seem to be pre-Illinoian,
because they extend upstream only to an elevation that is approximately
equivalent to the maximum elevation of outwash from the Bridgeport till at
the mouth of the valley at the junction with the Wisconsin River (Knox,
1982). Similar features occur in the Platte and Grant River valleys in the
southern Driftless Area, and they probably are of the same age as those in
the Kickapoo River valley.
While the Pleistocene cutoff valley meanders often appear similar in surface morphologic expression, some have deep fills of late Pleistocene sediments whereas others have shallow Pleistocene fills overlying a bedrock floor that is significantly higher than the local bedrock floor underlying modern floodplains. Drilling in the alluvial fills indicates that bedrock floors in the cutoff meanders are approximately 15 to 20 m higher than the bedrock floors underlying modern floodplains in the adjacent rivers for sites in the lower reaches of the Platte, Grant, and Kickapoo River valleys. If these cutoffs were initiated by the blockage of the drainage by pre-Illinoian glacial advances from the west, as suggested by the relationship with the Bridgeport till, then the bedrock floors of these relict river meanders may represent the degree of landscape incision that had occurred by classical Kansan time as defined by Trowbridge (1966). John Frye (1973), in reviewing the Pleistocene succession of the central interior United States, concluded (p. 279) that: "The early Kansan episode of erosion cut most major valleys to the maximum depth of their present bedrock valley floors." If one measures valley incision from the level of the Lancaster erosion surface to the level of the bedrock valley floors under modern floodplains, then the record of valley incision in the Driftless Area seems to support Frye’s conclusion. However, modest additional valley incision on the order of 10 to 15 m postdates the episode of early Pleistocene incision. Late Pleistocene incision, beginning about 160,000 years ago, has been documented at Mystery Cave in southeastern Minnesota (Milske and others, 1983). The later episode of incision may explain why no conclusive pre-Illinoian alluvial fills, or sediments with reversed polarity remnant magnetism, have been found in the valley fills and cutoff valley meanders in the Driftless Area (Knox, 1982).

In summary, deep valley incision in the Driftless Area occurred during early Pleistocene time prior to deposition of the Bridgeport till, a deposit that is correlative with pre-Illinoian tills of northeastern Iowa and northwestern Wisconsin. The abundance of pre-Illinoian outwash on Mississippi River bluff tops along the western margin of the Driftless Area supports the view that the placement of the Mississippi River and its deep entrenched valley also occurred during early Pleistocene time. Alluvial fills underlying modern floodplains and in cutoff valley meanders are mostly composed of Woodfordian sediments of late Wisconsinan age. Small amounts of older pre-Woodfordian sediments occur below the Woodfordian fills, but they are of unknown age. Tests of remnant magnetism in these pre-Woodfordian sediments indicate normal polarity and an apparent age that is younger than classical Kansan. Additional valley incision of 10 to 15 m has occurred since the early Pleistocene deep phase and may explain the paucity of early Pleistocene sediments in the valley fills.
PREGLACIAL DRAINAGE IN THE UPPER MISSISSIPPI VALLEY REGION

Richard C. Anderson
Department of Geology
Augustana College

Reconstructions of preglacial drainage in the Upper Mississippi valley region have in the past been based on the pattern of bedrock valleys. More recently it has been recognized that many bedrock valleys have been produced during Pleistocene time by glacial diversion and accompanying glacio-isostasy.

A more speculative approach to reconstruction of preglacial drainage is based upon considerations of paleoslopes, late Pliocene landscapes, and structural control. That preglacial drainage was to the south is generally agreed upon, and in fact, southward transport of sediment has persisted throughout Phanerozoic time. Little direct evidence of late Pliocene landscapes is available within the Upper Mississippi valley region itself, but reconstructions of that landscape in the central and northern Great Plains, in the Ozark Mountains, in the northern Mississippi Embayment, and in the Interior Low Plateaus of western Kentucky and Tennessee suggest that low relief characterized the surrounding regions. Furthermore, the distribution of iron-stained, Lafayette-type chert gravel indicates that physiographic continuity existed between the Upper Mississippi valley region and the surrounding areas. Thus it is reasonable to assume that the late Pliocene landscape of the Upper Mississippi valley region was also an area of low relief. The only elements of this landscape which remain are the chert gravels. It is unlikely that these are remnants of a blanket deposit which covered the whole landscape. They more likely represent channel deposits, which in turn imply the existence of valleys and stream courses. The distribution of these gravels is so scattered, however, that they offer no possibility for reconstruction of drainage lines. If on the other hand, the locations of these late Pliocene valleys and channels were structurally controlled, as was probably the case even on this surface of low relief, then a speculative, hypothetical reconstruction is possible.

The present course of the Mississippi River above the mouth of the Rock River is out of harmony with structure and thus is not the preglacial course. The dominant structure in this area is the Wisconsin Arch. The drainage pattern on such a structure might be expected to consist of master streams flowing radially outward generally perpendicular to the strike of the bedrock and joined by tributaries flowing parallel to the strike. This study suggests a single master stream flowing approximately along the axis of the arch, following a course which may have been roughly coincident with that of the modern Wisconsin River as far south as the Baraboo Range, which at that time had not yet been exhumed from its cover of Paleozoic sediments. From the Baraboo Range this hypothetical master stream may have continued south along a course marked by the modern Yahara River, Rock River, buried Paw Paw bedrock valley, and Illinois River. To the west it was joined by southeast-flowing tributaries represented today by the streams of northeastern Iowa and southeastern Minnesota. The Niagaran Escarpment may have been a significant divide on the east, imparting a distinct asymmetry to the drainage pattern. Nevertheless, at least one
important tributary entered from the east following a lowland on the Maquoketa Shale west of the Niagara Escarpment, a course marked by the present Rock River.

The details of the evolutionary history of the modern drainage from this hypothetical precursor are obscure, but perhaps certain generalizations are possible.

1. Glacio-isostatic effects, including a forebulge, were important.

2. The earliest glacial advances modified the drainage pattern in significant, but largely unknown, ways.

3. The earliest glaciations, advancing over a surface of low relief, were not as sharply constrained by bedrock lowlands as were later advances, and hence they may have followed different paths than the later advances.

ANCIENT VALLEYS—MODERN RIVERS
DIVERSION OF PREGLACIAL STREAMS BY THE ICE AGE

Edmund C. Bray
Hopkinson House
Philadelphia, Pennsylvania

By the comparison of maps, late Tertiary drainage of the central United States is compared with modern river systems. Emphasis is on the Missouri system, the Mississippi River, the Teays River, early drainage in eastern Ohio and northwestern Pennsylvania, and the formation of the Ohio River. Use of preglacial valleys by modern streams, frequently with reversed flow, is illustrated.

Six sets of maps are presented: for the Central United States, Western Region, Eastern Region, Ohio, Pennsylvania, Indiana, and Illinois. Each set includes a map of the preglacial drainage of the region, one of modern drainage and one superimposing the former on the latter.

The material on which this presentation is based has been gathered by an extensive search of scientific publications, but the author realizes that knowledge is inadequate for making the treatment conclusive or accurate in detail.
The Quaternary geology of southeastern Minnesota has been little studied since the comprehensive work of Leverett (1932). Recent work by the Minnesota Geological Survey in Winona County (Hobbs, 1984), however, has suggested new concepts which I will attempt to apply to the whole region.

We cannot at present map the surficial deposits of southeastern Minnesota in any detail. However, the area can be divided into five zones based on the thickness and relative age of the glacial deposits. From east to west they are: the unglaciated zone, the "residual" till zone, the St. Charles zone, the thick drift zone, and the Des Moines lobe zone (Fig. 1). I will restrict my discussion to the zones east of the Des Moines lobe, which are covered by discontinuous late-Wisconsinan loess. Inasmuch as the colluvium and terrace deposits in the valleys are predominantly late Wisconsinan in age and are not diagnostic of any one zone, the zone definitions and descriptions are based on the sediments that occur on the interfluves.

Unglaciated Zone

Early geologists recognized a "Driftless Area" in southwestern Wisconsin and adjacent parts of Minnesota, Iowa, and Illinois where the landscape is characterized by deeply incised streams, all tributary to the Mississippi River. However, remnants of till have been discovered on the interfluves in parts of the "Driftless Area" in Iowa (Trowbridge, 1966). This discredited the concept of the "Driftless Area" in Iowa, thus raising doubts about whether there was actually a driftless area in the Upper Midwest. Knox (1982) has shown that the bulk of the driftless area in Wisconsin was unglaciated. Hobbs (1984) has shown that at least a small part of extreme southeastern Minnesota also remained unglaciated. The edge of the unglaciated area in southeastern Minnesota cannot be recognized as a geomorphic boundary because of extensive dissection and erosion.

In the unglaciated zone shown on Figure 1, neither till nor erratics were observed. The gentle slopes on the interfluves are mantled with reddish-brown to brown sediments derived from chemical weathering of the bedrock. Carbonate rocks weather to cherty clay, and sandstone weathers to sand and cemented sandstone clasts. The sand and clay are mixed and interbedded in places, are variable in thickness, and commonly fill in bedrock lows, solution cavities, and sinkholes. This suggests that much of this material has been transported and redeposited, presumably by slope wash and mass movement. I will use the term "residuum" for all sediments left from chemical weathering of the bedrock, whether in-place or redeposited. The term "colluvium" will be used for more recent sediments on valley sides that were derived predominantly by mechanical weathering.
Residual Till Zone

In this zone, the residuum is still fairly thick, and the degree of dissection on the bedrock surface is about the same as in the unglaciated zone. However, erratics and patchy till, informally known as "residual" till, are present. In some places, no till is preserved on the bedrock surface, but erratics and till-like materials are present in sinkholes. The "residual" till is completely oxidized and leached; its texture is variable, ranging from sandy loam to clay. Its characteristically low silt content results from local incorporation of residuum.

St. Charles Zone

In the St. Charles zone, residuum is preserved in caves and sinkhole fillings, but does not cover extensive areas of bedrock. Bedrock is overlain by till, mapped as "Kansan" by Leverett (1932). The till has a loam to clay-loam texture, and is gray and calcareous where unoxidized and unleached. This till has been informally named the St. Charles till in western Winona County, where it has been studied in some detail. In the eastern part of the St. Charles zone, the till is fairly thin (7 m or less). In the western part of the zone, the drift is locally thick (30 m and greater); the surface till has the same general nature as that of the "type" St. Charles till. In places the thickness is presumably a result of old moraines; in other places, the till fills buried bedrock valleys. The stratigraphy of these thick deposits is unknown.

Figure 1. Generalized Quaternary geology of southeastern Minnesota.
Thick Drift Zone

Bedrock landforms, predominantly dissected plateaus and escarpments, dominate the morphology of the unglaciated and residual till zones and the eastern part of the St. Charles zone. To the west, the bedrock landscape is progressively smothered by glacial deposits. The line between the St. Charles zone and the thick drift zone was drawn where the bedrock topography can no longer be discerned on topographic maps. The underlying bedrock contains deep, steep-sided valleys similar to those at the surface farther east. The dissection of the thick drift has created fairly gentle slopes from the interfluves to the valley bottoms. In contrast, areas dominated by bedrock morphology commonly have steep-sided valleys separated by gently sloping interfluves.

The surface till is generally gray and calcareous, as in the St. Charles zone. However, in the southern part of the thick drift zone, a paleosol commonly underlies a thin reddish-brown till containing pebbles from the Lake Superior region, which appears to be a pre-Wisconsinan Superior lobe till. Perhaps it correlates with the red drift of the Hampton moraine, which Leverett (1932) considered Illinoian.

Landscape Evolution

A fundamental question about the evolution of the Upper Mississippi River valley is whether the deeply incised landscape is a remnant of a preglacial topography, elsewhere buried by glacial deposits, or whether it originated during the Quaternary. The early geologists assumed the former; my view is that the Mississippi River now occupies the course of an ice-marginal stream, which formed during the first extensive glaciation of the area, in a manner analogous to the formation of the Missouri and Ohio Rivers. All of these rivers approximate the boundary between glaciated and unglaciated regions. Once in its present position, the Mississippi downcut more rapidly than competing streams and dismembered the preexisting stream network. It is quite possible that the preglacial streams were not as deeply incised as the present network, and that for this reason the modern landscape shows no surface trace of a stream network other than the modern one. There also is no evidence for a buried stream network which crosscuts the modern one. Buried valleys in the Twin Cities area are all tributary to the Mississippi, so if they are preglacial, the Mississippi must also be preglacial. However, I suggest that the buried bedrock valleys were carved, as well as filled, possibly during several pre-Wisconsinan cycles.

Let us now consider how the landscape of southeastern Minnesota has changed with time. Theoretically, we would expect the Mississippi and its tributaries to have gone through many cycles of downcutting and aggradation, controlled by sea level, outwash deposition, and glacial lake drainage. These short-term events make it difficult to distinguish between a pre-existing dissected landscape and one developed during the Pleistocene. In fact, only the most recent cycle (late Wisconsinan and Holocene) is known in any detail; the earlier record is quite scanty. I suggest that a relatively undissected landscape existed prior to glaciation—a landscape consisting of plateaus of Paleozoic rocks mantled by thick residual soil. Sinkholes were forming and filling with residuum, as they had since
pre-Cretaceous time. Unconsolidated Cretaceous clay and sand occupied bedrock lows that are now high above base level. The rocks of the Prairie du Chien group had probably not yet been breached by streams.

The Quaternary period was marked by numerous cycles of fluvial downcutting and backfilling, with downcutting predominating over the long run. Ice sheets advanced generally from west to east over the plateaus, scouring off much of the residuum and leaving till. Deposits of loess blanketed the landscape several times, only to be eroded, leaving remnants to be buried by later advances. Ice margins occupied this comparatively small region from the earliest advance to reach southeastern Minnesota to the most recent one. Valleys were eroded in bedrock and filled with glacial deposits.

Conclusion

It will take much work to test the ideas associated with relatively rapid erosion and downcutting occurring during the Quaternary. Here are some suggestions for future research: The glacial stratigraphy must be worked out in much greater detail and correlated with adjacent states. We would like to know the base level for the Upper Mississippi throughout the Quaternary. We need to date the karst development and correlate these dates with the glacial sequence. We need to determine the composition and stratigraphy of the sediments within the buried valleys. Do any of the valleys contain preglacial sediments? It is unlikely that we can find all the evidence we need in Minnesota; it is only by a combined effort in several states that the geologic history of this region can be understood.
OBSERVATIONS ON THE EVOLUTION AND AGE OF THE BEDROCK SURFACE IN EASTERN IOWA

G.R. Hallberg, B.J. Witzke, E. Arthur Bettis III, and G.A. Ludvigson
Iowa Geological Survey

The evolution of the Paleozoic bedrock surface in eastern Iowa has involved a complex history of subaerial (and subglacial) erosion, burial, and exhumation from the Mesozoic through the present. In much of the geologic literature dealing with the Paleozoic plateau region there is a presumption of great antiquity for deep bedrock valleys and other features, simply because they are cut into "bedrock." Unfortunately, the erosional evolution of this (or any) region is in the form of a missing record, but there are "patches" of evidence that afford some insights.

The Windrow Formation is a Cretaceous rock unit preserved at several localities in northeastern Iowa and nearby areas of Wisconsin and Minnesota, primarily along drainage divides at elevations between 330 and 440 m (Thwaites and Twenhofel, 1921). The Windrow Formation includes an iron-rich (limonitic) basal unit and an overlying interval of sandstone and gravel that is commonly iron-oxide-cemented. The basal Windrow in northeastern Iowa is characteristically found on karstic surfaces of Ordovician and Devonian limestones and dolomites. Large solution-pitted blocks of Ordovician limestone (Dunleith Formation) are noted within the basal Windrow iron-rich unit in Allamakee County (Howell, 1916, p. 66), and a Windrow Formation exposure in Mitchell County "fills an erosion channel in the underlying Devonian limestone" (Thwaites and Twenhofel, 1921, p. 300). Windrow sediments locally fill solutional fissures in the carbonate bedrock units. In general, the carbonate surface that underlies the Windrow Formation is "badly weathered" and exhibits "structures produced by solution activity" (Andrews, 1958, p. 606). The basal iron-rich unit fills in portions of the underlying paleokarst surface and replaces some of the carbonate rock. This unit may have accumulated as an iron-rich residuum in a humid subtropical Cretaceous climate, and the iron may have been further concentrated through fluvial processes or in bogs (summary in Witzke and others, 1983).

Above the basal iron-rich unit the Windrow Formation is primarily a fluvial sandstone and gravel unit. Cross-strata orientations at scattered Windrow exposures indicate that fluvial transport directions were generally toward the west and southwest (Andrews, 1958; see also Fig. 1). Windrow sediments (sands, gravels, clays) were derived from terranes to the east and northeast (Witzke and others, 1983). The Cretaceous stream systems initially aggraded as a seaway encroached eastward across Iowa. Ultimately the seaway probably covered much or all of the state including the northeastern portion, although subsequent erosion has removed most evidence of marine sediments from the northeastern Iowa area (ibid.). Evidence of later Cretaceous sedimentation in the study area is absent because of an extensive period of Cenozoic erosion.

The amount of post-Cretaceous downcutting in the northeastern Iowa region can be approximated where Windrow fluvial deposits are still pre-
Figure 1. Schematic view of the landscape inversion that has taken place since the Cretaceous in northeastern Iowa: Top, Cretaceous landscape; bottom, modern land surface.
served. In general, the fortuitous preservation of outliers of Windrow Formation fluvial deposits along some high drainage divides indicates that aggrading Cretaceous fluvial systems occupied a different position relative to modern fluvial systems (Fig. 1). Assuming that local post-Cretaceous structural displacements have been generally insignificant in northeastern Iowa, the relative difference in base levels of Cretaceous and modern fluvial systems provides a basis for estimating post-Cretaceous downcutting. The modern Mississippi River valley represents the lowest local base level in northeastern Iowa. On the other hand, Cretaceous Windrow fluvial systems initially aggraded within paleovalleys now about 150 to 240 m above the level of the Mississippi. This observation suggests that at least 150 to 240 m of post-Cretaceous downcutting has occurred in the northeastern Iowa area. Howell (1916, p. 82) arrived at a similar conclusion and suggested about 180 m of post-Cretaceous downcutting. More important, perhaps, than the depth of downcutting is the topographic inversion that has taken place. In general, only the lower portions of the Cretaceous landscape are now preserved, on or near the top of the present landscape; Cretaceous uplands have been largely or entirely removed by erosion. If the depth of karst development in the Cretaceous was related to the depth of entrenchment of major river valleys (because of their influence on ground-water flow), then most of the Cretaceous upland karst landscape has been totally removed. The degree of post-Cretaceous erosion and downcutting in northeastern Iowa implies that most or all of the now active karst systems in the area are post-Cretaceous in age.

Previously suggested relationships between the sub-Windrow paleokarst surface in the iron pits of Fillmore County in southeastern Minnesota and nearby active karst terrains remain unclear. The modern upland Paleozoic bedrock surface in that area is roughly coincident with the sub-Cretaceous surface. Any of several possibilities may explain the development of modern active karst in that region: (1) The sinks and caves are exhumed and reactivated Cretaceous systems that have been "flushed" of their sediment fill; (2) shallow solutionally enlarged fissures and flutes (lacies) 1 to 10 m deep on the sub-Cretaceous surface may have predisposed that surface for later and deeper Quaternary karst development as base levels were lowered by stream incision; (3) the modern karst systems are superimposed on the sub-Windrow paleokarst surface but are entirely the result of later processes. Ultimate verification of the first alternative requires recognition of preserved remnants of in-place Cretaceous rocks within the walls or crevices of active sinks and caves, but no such evidence has been presented to date. The sub-Cretaceous surface has been erosionally removed over most of the Upper Mississippi valley area, and most modern karst systems in the area are unrelated to Mesozoic karst development.

The general transport direction of Windrow fluvial systems toward the west and southwest contrasts markedly with the modern situation in northeastern Iowa where stream and river systems generally drain toward the south and southeast (Fig. 1). The Cretaceous fluvial systems drained generally westward toward a vast north-south oriented seaway that occupied the Western Interior of North America (Witzke and others, 1983). As such, the southward-draining Mississippi River tributary system was clearly absent in the general study area during the Cretaceous. This observation indicates that the incision of the Mississippi River drainage system in the northeastern Iowa area was entirely a post-Cretaceous development.
There is almost no record of Tertiary events in this region, except the removal of the Cretaceous landscape described above. The "Lafayette"-type gravels (or Mounds and Grover Gravels of Illinois) in the Upper Mississippi valley are assumed to be late Tertiary in age and they show features similar to the remnant Cretaceous deposits: They are also fluvial deposits, which are preserved in isolated patches on present bedrock uplands, but were deposited in a more southward-trending drainage system. As noted to the south in Illinois (Willman and others, 1975), these deposits suggest at least 90 m of stream downcutting since the late Tertiary. This again suggests removal of much of the Tertiary upland landscape.

All of eastern Iowa was glaciated during the Quaternary (i.e., there is no Driftless Area in Iowa). In many regions of Iowa the bedrock surface is deeply buried by Quaternary deposits. The buried bedrock surface exhibits ridges and valleys reflecting a complex fluvial history. The bedrock valleys may range widely in age, but generally are thought to be Pleistocene (see Frye, 1963; Willman and Frye, 1970; Hallberg and others, 1984). In many areas of Iowa these bedrock valleys are buried by 75 to 100 m or more of Quaternary deposits. In few areas there are enough drill-hole data to reconstruct the relationship between buried valley segments accurately. In areas with sufficient data, the bedrock valley configuration and the overlying stratigraphy clearly show that what might appear to be a "single" drainage network is really a multi-generation surface: Hanging valleys cut across other deep valleys, and valley segments of different ages criss-cross. In eastern Iowa, deposits of 4 to 5 different pre-Illinoian glacial events (Hallberg, 1980a) all directly overlie the bedrock in different areas. During each glacial and interglacial period, glacial and fluvial erosion may have downcut to the bedrock surface and superposed a new valley on this surface, just as the streams of today are cutting across the partially exhumed bedrock topography. In eastern Iowa the deepest and most prominent buried valley segments are consistently filled with deposits of the pre-Illinoian Alburnett Formation (Hallberg, 1980a). Data from south-central Iowa suggest that this entrenchment took place between about 1,000,000 and 2,000,000 years ago, during the Quaternary. During these periods of entrenchment some karst development may have taken place, but there is no evidence to substantiate this.

In eastern Iowa the bedrock surface, including the buried valleys, is being exhumed. In the northeastern corner of Iowa in the Paleozoic plateau region, these valleys have been totally exhumed and exposed along modern valley walls. These exhumed valleys are filled with till and glaciofluvial deposits and cut across the modern drainage. These observations coupled with the widespread occurrence of till across the uplands indicate that the modern drainage network (in Iowa at least) could not have begun to develop until after the last glacial event in the region about 500,000 years ago.

The general thought among Quaternary geologists, for some time, has been that the modern drainage system and deep entrenchment occurred in the Pleistocene, and that the Upper Mississippi River valley originated as an ice-marginal stream during "Nebraskan" glaciation (Trowbridge, 1921, 1966; Willman and Frye, 1970). Although we would not now date this drainage derangement as "Nebraskan," evidence (Frye, 1963; Trowbridge, 1966; Willman and Frye, 1969, 1970) still supports the Pleistocene age for establishment
of the Upper Mississippi River and the modern bedrock-valley system. In addition to the evidence discussed here, these authors also note that: (1) The valley is out of adjustment with the bedrock stratigraphy and structure; (2) topographically high outwash in Illinois has been related to till on the uplands in Iowa, clearly suggesting that no intervening valley was present; and (3) other related deep valleys, which also are out of adjustment with the bedrock, were either ice-marginal or were deranged by Pleistocene ice sheets.

Any system, given sufficient time, even if superposed, will adjust its valley in accord with local bedrock structure. Indeed, segments of the entrenched Upper Mississippi drainage net are in accord with local structure. However, contiguous segments are not adjusted to structure, and overall the system is not aligned with important regional structures (e.g., Anderson, this volume).

In sum, the available evidence suggests that most of the current bedrock topography (and karst features) are Quaternary in age; most of the pre-Quaternary landscape has been removed. Though it seems likely that some of the known bedrock topographic and karst features in the Paleozoic plateau may be paleokarst or pre-Pleistocene, there is little evidence to substantiate that these constitute significant portions of the paleo-landscape.
CONTRASTING AGE OF THE MISSISSIPPI RIVER VALLEY
IN EAST-CENTRAL MINNESOTA
AND ITS TRIBUTARIES IN WEST-CENTRAL WISCONSIN

Robert W. Baker
Department of Plant & Earth Science
University of Wisconsin-River Falls

Ongoing surface and subsurface investigations suggest that many of the major tributaries to the Mississippi River in western Wisconsin--namely the Kinnickinnic, Trimbelle, Rush, Chippewa, and Buffalo Rivers--have experienced at least one, and possibly two, major flooding events by ice-dammed lakes. The younger flooding event occurred when a glacial lobe advanced into western Wisconsin from the northwest resulting in an interconnecting network of proglacial lakes covering an area of almost 6000 km$^2$. Paleomagnetic analyses of the varved sediments deposited in the lakes indicate that deposition spanned a reversed-to-normal polarity transition, probably the Matuyama-Brunhes transition which occurred approximately 730,000 years ago. These data suggest that many of the rivers in western Wisconsin have occupied their present valleys for over half a million years, in spite of the fact that during this interval of time, all or parts of these valleys have been overridden during one or more glacial episodes.

The apparent antiquity of the river systems in Wisconsin seems to be anomalous when compared to adjacent east-central Minnesota. Specifically, this part of Minnesota is underlain by a complex network of buried river valleys that range in width from 0.4 to 2.2 km and are as much as 0.2 km deep. Because they are now drift-filled, it has been suggested that this network of valleys developed through multiple episodes of erosion during interglacial stages, whereby rivers such as the ancestral Mississippi occupied new courses after each glacial event. If this scenario is correct, it is in conflict with evidence from western Wisconsin where the river systems appear to have reoccupied the same lowlands after successive glacial events, for at least 730,000 years.
THE BEDROCK GEOLOGY OF SOUTHERN MINNESOTA AND ITS RELATIONSHIP TO THE HISTORY OF THE MISSISSIPPI RIVER VALLEY

Bruce M. Olsen
Minnesota Geological Survey

The valley of the Mississippi River is entrenched into Paleozoic bedrock from Minneapolis to the Iowa border. The contention that the valley is out of adjustment with bedrock stratigraphy and structure led to the supposition that the Mississippi River was an ice marginal stream established during the Pleistocene. Also, the absence in southeastern Minnesota of deposits identified as of Tertiary age, together with Pleistocene radiometric ages obtained from speleothems, supports the idea of glacial origin of the valley. However, evidence for the Quaternary development of the valley is based on studies and observations from a rather limited area--mostly counties that border or are near the Mississippi River. The bedrock geology for the remainder of the southern half of Minnesota has been viewed as having little if any impact on the geomorphic history of the Mississippi valley. Nonetheless, a review of the regional bedrock geology provides a perspective which suggests that the arguments for a young age may not be totally valid. It also raises questions concerning the age of the Mississippi valley relative to the age of a regional network of buried bedrock valleys.

Position of the Mississippi Valley

The position of the Mississippi River valley in southeastern Minnesota is not out of alignment with the bedrock geology and can be explained by an analysis of the regional structure and bedrock topography.

The Mississippi River valley trends along the eastern margin of a shallow basin termed the Hollandale embayment (Austin, 1969). This basin lies between the Wisconsin highlands east of the Mississippi River and the Transcontinental Arch which transects south-central Minnesota (Fig. 1). Devonian and Ordovician dolostones and limestones occur as the uppermost bedrock throughout much of the Hollandale embayment and generally dip toward its center at less than a 1-degree angle. As a result, the bedrock units are almost flat lying, and bedrock resistant to erosion creates a gently rolling terrain called the southeastern Minnesota carbonate highlands. The most notable exception is in the Minneapolis-St. Paul area, where the Twin Cities basin occurs as a small structural basin within the Hollandale embayment. Consequently, the Twin Cities area is a structural and topographic lowland in relationship to the rest of southeastern Minnesota. This lowland has caused bedrock drainage systems over most of the southern half of Minnesota to drain toward the Twin Cities basin where bedrock elevations are low enough for water to enter the Mississippi valley (Olsen and Mossler, 1982a).

The bedrock canyon now occupied by the Mississippi River in southeastern Minnesota is the master bedrock drainage for the southern half of Minnesota: no other master channel is known to occur (Mossier, 1983). Its position has not shifted because it is entrenched through the stratigraphically lowest resistant unit of the area--the Prairie du Chien Group (Lower
Ordovician). The Mississippi valley trends in a direction parallel to the strike of the Prairie du Chien strata and thus in a direction parallel to the eastern margin of the Hollandale embayment. The Mississippi could not position itself farther to the east, where rocks of the Prairie du Chien Group no longer exist and less resistant strata of Cambrian age occur, because this area is along the western flank of the Wisconsin highlands and consequently has a higher elevation. West of the Mississippi valley, the Prairie du Chien Group caps an extensive bedrock plateau before it ultimately is buried beneath younger, but topographically higher bedrock. Thus the Prairie du Chien plateau appears to have been a regional lowland situated between the Wisconsin Arch on the east and an escarpment of younger bedrock to the west even before entrenchment of the Mississippi valley began (Fig. 2).

The position of the Mississippi canyon in relation to the boundary of the Prairie du Chien plateau was probably influenced by local structural controls. Although the regional dip is low and to the southwest, very local antiformal and synformal structures with closures of as much as 30 m occur along tributary valleys. Also, jointing has strongly influenced the directions of tributary drainage. Thus, it is plausible that these structural attributes influenced incipient drainage and downcutting in the Prairie du Chien plateau. Once the Prairie du Chien was breached, the underlying 240 m of less resistant Cambrian strata would have ensured entrenchment and widening of the original drainage system into the present canyon.

In summary, the position of the Mississippi valley in southeastern Minnesota is in harmony with the bedrock geology. Glacial processes need not be called upon as the sole or even major cause for its present location.

Buried Bedrock Topography

The bedrock surface of most of the southern half of Minnesota is buried by Quaternary deposits which may exceed 180 m in thickness (Olsen and Mossler, 1982b). The buried bedrock topography contains numerous valleys, all of which drained into the Mississippi valley. The elevations of the bedrock surface in some buried valleys suggest that the Mississippi valley would have had to have been incised through the entire Cambrian section near the Iowa border in order for it to have served as the master drainage before the valleys were filled by Quaternary deposits. Furthermore, some of these valleys trend in directions oblique to or even reverse to the directions of regional glacial advance and retreat. Unfortunately, the subsurface Pleistocene stratigraphy of southern Minnesota is not well understood, and no determination can be made as to the age of most of the bedrock valley fill materials. A thorough study of the buried bedrock valleys would not only add to our knowledge of the Quaternary stratigraphy of the Upper Midwest, but also may aid significantly in determining the age of the Mississippi River valley. Until the stratigraphic problems posed by buried bedrock valleys are solved, any explanation of the geomorphic development of the Mississippi River valley will not be complete.
Figure 1. Regional bedrock structures.

Figure 2. Schematic diagram of the Mississippi River valley in southeastern Minnesota prior to entrenchment.
Resistance of Bedrock to Meltwater Erosion

Buried bedrock valleys are deeply incised into Precambrian crystalline bedrock in southwestern Minnesota, and are entrenched into Paleozoic carbonate bedrock in the Hollandale embayment. Glacial River Warren, however, had little erosive impact as it flowed over these bedrock types, even though it was the largest drainage event of late Wisconsinan time. Given the complex distribution of buried bedrock valleys in resistant bedrock types in the southern half of Minnesota, it would appear difficult to account for all of them as the result of erosion by glacial processes—especially for those whose headwaters appear to be reversed to the general directions of ice retreat. Also, a history of backfilling would need to be developed to relate the subsurface Pleistocene stratigraphy to the distribution of buried bedrock valleys. If that is possible, a Quaternary age for the Mississippi River valley in southeastern Minnesota could more readily be explained.

Deposits of Tertiary Age in Southern Minnesota

No studies have satisfactorily documented the existence of Tertiary strata in Minnesota. However, alluvial and colluvial deposits that would have accumulated along pre-Quaternary bedrock valleys may be indistinguishable from the same type of deposits now forming from local bedrock as the only source material. Furthermore, no systematic search for paleontological evidence has been undertaken. Therefore the fact that deposits of Tertiary age, which would indicate the existence of the Mississippi valley in Tertiary time, have not been confirmed, need not mean that they do not exist.

Summary

The history of the Mississippi River valley in southeastern Minnesota reflects geologic processes that occurred throughout the southern half of Minnesota. The bedrock geology has influenced the position of the Mississippi valley and provides a framework for working out the geomorphic development of southeastern Minnesota. However, a greater understanding of subsurface Pleistocene stratigraphy must be obtained before relationships between the buried bedrock topography and the downcutting and backfilling of the Mississippi River valley can be determined.
INFLUENCE OF STRUCTURE AND ROCK TYPE ON THE FORMATION OF BEDROCK VALLEYS IN THE TWIN CITIES AREA, MINNESOTA

Mark A. Jirsa
Minnesota Geological Survey

The development of major stream systems in the seven-county Twin Cities area was partly controlled by physical and structural characteristics of the bedrock. Because this is the northernmost area where the Mississippi River and its tributaries cut into Paleozoic sedimentary rocks, this study establishes a framework for valley development in the larger Mississippi drainage system.

Bedrock geologic and topographic mapping (Jirsa, in prep.) indicates that contrasts in competence (resistance to erosion) between particular rock units had a pronounced impact on the present gross distribution of rock types and the location of bedrock valleys. The map area is dominated by wide plateaus of competent dolomite and limestone which are separated by relatively narrow valleys that were cut through them into less competent sandstone and shaly sandstone.

A lineament analysis of bedrock topography indicates significant trends at N.45°E., N.45°W., and N.5°E. Thus the orientation of valleys which dissect the competent formations appears to have been structurally controlled.

The deposition of the Paleozoic rocks occurred in the Hollandale embayment, a sedimentary basin underlain by middle Proterozoic volcanic and sedimentary rocks. The Proterozoic rocks contain northeast-trending (N.42°E.) magnetic lineaments inferred to be block faults. The block faults presumably were offset by strike-slip faults inferred from northwest-trending (N.45°W.) lineaments. These Proterozoic structural elements were locally remobilized to produce similarly oriented faults and folds in the overlying Paleozoic rocks.

The reactivated structures in the Paleozoic rocks vary from being moderately well exposed to being completely obscured by glacial drift. All of the known faults appear to have localized valley formation by juxtaposing rock units with contrasting competences and by creating sufficient structural weakness to facilitate stream erosion through competent rocks into less competent rock units. The location of valleys in relation to anticlines, synclines, and similar structures is less consistent, but valleys commonly exist parallel to fold axes. These valleys occur along the limbs of the fold structures, or are coincident with axial traces. The anticlinal features have influenced drainage patterns in three ways: (1) The uplifted competent units produced effective flow blockage causing valley formation peripheral to the structure along the fold limbs; (2) the fractures that opened during deformation provided linear weakness which localized valleys; and (3) in areas of competent rock subcrop, upwarping raised less competent rock to a higher level of erosion causing axis-parallel valley formation.

Joint sets are ubiquitous in the Paleozoic rocks, but their impact on the formation of bedrock valleys is problematic. A non-systematic study of
joints (634 measurements) indicates that major joint trends are subparallel to the prominent trends of lineaments on the bedrock surface. This implies that some direct relationship exists. Areas of closely spaced joints parallel to the major trends may have localized valleys; however this cannot be proved because areas of closely spaced joints probably are deeply eroded and now filled with unconsolidated materials.

The summary of all orientation data on Figure 1 illustrates the coincidence of Proterozoic and Paleozoic bedrock structure with the orientation of bedrock valleys. The relationship between these data and surface drainage patterns varies: Where bedrock is relatively close to the land surface, as in much of the Upper Mississippi valley, the surface drainage is superimposed on the bedrock valley system with only minor modification. This coincidence of valleys is less consistent in areas where the bedrock surface is significantly below the land surface. However, even in such areas, differential compaction of unconsolidated materials that fill larger bedrock valleys created quasi-linear lowlands which locally contain surface drainageways with similar, though less well defined, orientations.

These data indicate that the bedrock geology played a major role in the developmental history of the Upper Mississippi River system in the Twin Cities area and probably elsewhere. Therefore, glacial processes need not be invoked to totally explain that development.

---

Figure 1. Summary of orientation data, Twin Cities area; t, bedrock topography lineaments (n=328); j, joints (n=634); p, linear structures in Paleozoic bedrock (fold axes and faults, n=20); pr, linear structures in Proterozoic bedrock inferred from geophysical data (n=35); number to right of symbol denotes primary, secondary, and tertiary structural components by abundances.
The fluvial geomorphology of southeastern Minnesota is entirely Pleistocene in age. The location of the Mississippi River downstream of the Cannon River was determined by an early Pleistocene ice margin of a Des Moines-type lobe. This is shown by shape of the river, by the remains of the old till sheet now preserved on the uplands (Hobbs, 1984), and by the fact that the course of the river follows neither a geologic contact nor an old topographic low. Instead it climbs over the crest of a topographic dome (Fig. 1). This dome has subsequently been dissected and incised to a depth of as much as 210 m by the drainages of the Mississippi and tributary rivers. The major tributaries of the Mississippi are either consequent on the Wisconsinan morainic topography or were located by the meltwater from a Des Moines-type lobe later than the one that located the Mississippi River. This glacial lobe and the accompanying moraine is the one termed "Old Gray drift" by Leverett (1932) and "Kansan" by Ruhe and Gould (1954). This moraine is deeply dissected and most easily located by the large boulders of Archean and Proterozoic rocks too large to be removed from farmers' fields. Meltwater from this moraine formed meanders in the master streams, the Zumbro and Root Rivers, with a maximum wavelength of 6 to 10 km. These meanders are now deeply entrenched.

Subsequent to the establishment of the main streams of southeastern Minnesota there were a number of cases of stream piracy. Seven have been identified south of the Twin Cities, and others probably exist. Several are associated with exhumation of a Cretaceous valley fill in a Cretaceous valley carved in the Paleozoic Redwing-Rochester anticline. The most northern (1 on Fig. 2) is in eastern Goodhue County, south of Redwing, where Hay Creek stole the headwaters of Wells Creek. Only a low divide of 15 m of Lower Ordovician Oneota Dolomite less than 0.4 km in width prevents a second theft of the headwaters of Wells Creek by Hay Creek. These piracies are along the crest of the anticline.

The next piracies are along the Zumbro River. Originally the Zumbro headed near Danesville in western Olmsted County and flowed directly toward the Mississippi River passing near the present town of Oronoco (2 on Fig. 2). A significant lithified channel sandstone, more than 30 m thick, of this river is present 1 mile southwest of the town of Hammond (3 on Fig. 2). Bear Creek and the North Fork of the Zumbro eroded headward into the Cretaceous valley fill northwest of Hammond and cut down through the Oneota into the soft Croixan sandstones along the crest of the anticline. A branch of the North Fork then cut south along the crest of the anticline, ultimately stealing the headwaters of the Zumbro itself. It then continued to entrench southward, next stealing the headwaters of the Whitewater River as shown by the high river sands near Highway 14 between Dover and St. Charles (4 on Fig. 2).

During the entrenchment of the Root River at least two high cut terraces in meander loops were abandoned by meander cutoff and left stranded.
Figure 1. Map of southeastern Minnesota and adjacent parts of Wisconsin and Iowa showing the highest elevation on present divides for each 15-minute quadrangle. This is the best representation of pre-Pleistocene topography and shows that the present course of the Mississippi River is not consequent on that topography.
Figure 2. Recent and pre-Wisconsinan drainage and piracy in southeastern Minnesota.
30 m above the present floodplain. One is 4.8 km below Rushford (5 on Fig. 2) and the second is 9.6 km below Houston (6 on Fig. 2). In view of the dated levels of the Root River at Mystery Cave, these terraces would appear to be pre-Wisconsinan in age.

There is extensive karst stream piracy in Fillmore County. The most thoroughly documented is Mystery Cave (Milske and others, 1983; 7 on Fig. 2). The Root River has flowed through the cave throughout Wisconsinan time. At least 30 m of incision had taken place by the early Wisconsinan when the oldest speleothem in 5th Avenue was deposited; 18 m more of incision took place during the Wisconsinan, and the flow is now 12 m lower than that.

The present broad floodplain of the Cannon River is due to meltwater of the late Wisconsinan Des Moines lobe having stripped away the loosely consolidated St. Peter Sandstone from the underlying resistant Shakopee dolomite. Pinnacles such as Chimney Rock (8 on Fig. 2) are then Holocene in age.

Throughout the Pleistocene the Twin Cities Metropolitan Area was always the junction of three major drainages. The largest of these was always the Minnesota River or Glacial River Warren, draining Lake Agassiz in the Red River Valley. Next in size was the St. Croix River draining Glacial Lake Duluth in the Lake Superior basin; least in size was the Mississippi River, draining only the interlobe area of central Minnesota. Multiple waterfall-retreat gorges that are now buried in Wisconsinan till and outwash are known (Schwartz, 1936; Payne 1965; Wright, 1972). No one has dated or suggested an order of incision of these valleys, although presumably there was at least one set of three valleys for each of the major ice advances.

A radial drainage pattern exists around the Witoka structural dome (9 on Fig. 2). Multiple depositional terraces exist in the Cannon River valley near the Mississippi River (Crain, 1957); these were mapped when only inadequate topographic maps were available. They should be remapped and traced into other terraces in the Twin Cities and in the Zumbro and Root River valleys.

The Pleistocene mammals known are all apparently Wisconsinan in age (Stauffer, 1945).
KARST AND THE PLEISTOCENE HISTORY OF THE
UPPER MISSISSIPPI RIVER VALLEY

R.S. Lively and E.C. Alexander, Jr.
Minnesota Geological Survey and
Department of Geology and Geophysics
University of Minnesota, Minneapolis

Paleozoic limestone and dolostone throughout the Upper Mississippi River valley have extensively developed solution cavities, sinkholes, and subsurface drainage features, forming a typical karst landscape that extends from the edge of the carbonate platform in central Minnesota, southward for hundreds of miles along both sides of the Mississippi River valley. The geologic histories of the karst and Upper Mississippi River valley are interrelated in that both developed concurrently during Pleistocene and possibly pre-Pleistocene time. Bedrock solution and subsurface drainage, together with surface erosion, were primary mechanisms for shaping the regional geomorphic surface.

The establishment of an integrated surface drainage with deeply incised valleys lowered the regional water table. Solution cavities that had developed near or below the water table were abandoned, and new solution features evolved at lower elevations. Evidence of this can be seen today, in the form of phreatic tubes and caves located in bluffs of the Prairie du Chien Group, at several elevations as much as 100 m above the present water table. Conversely, as the karst matured and subsurface drainage increased, piracy of surface streams and drainage resulted in the development of blind valleys, dry valleys, sinkholes, and other karst features. It is also possible that some abandoned meanders in bedrock along surface streams resulted from subsurface stream piracy.

Studies of the karst and its connection with the history of the Mississippi River valley are still in the early stages. Although karst processes have operated sporadically in the region since Paleozoic time, the periods of deep bedrock incision and the glacial activity during the Pleistocene undoubtedly had a major influence on the existing karst and on the development of new karst. U-series dating of speleothems from caves throughout the region have shown episodic calcium carbonate deposition correlative with interglacial and interstadial periods over the past 350,000 years, and periods of reduced or zero deposition during glacial cycles. Major deposition occurred from 160,000 to 100,000; 60,000 to 30,000; and 15,000 years ago to the present. Older periods of deposition are known between 160,000 and 350,000 years ago, but they are not yet well defined. Because of extensive speleothem deposition beginning at 160,000 years, we can argue that the climate at that time in southeastern Minnesota was not as severe as that during the late Wisconsinan glacial stage, when speleothem deposition ceased. Thus southeastern Minnesota appears to have been free of ice and permafrost at a time when the sea-level record indicates a maximum in ice volume, presumably concurrent with the existence of continental glaciers.

Some fluvial sediments capped with dated flowstone within Mystery Cave in southeastern Minnesota are pre-Wisconsinan (>145,000 years) in age,
whereas some were deposited and then covered with flowstone at the end of the Wisconsinan (>12,000 years). Other silt-size sediments, which commonly fill large passages, have not yet been dated and could represent a period(s) of back-flooding when the Root River was dammed, possibly as the result of glacial activity.

The course of the Root River at Mystery Cave is a long meander around hills cored by the Galena and Dubuque Formations. Mystery Cave serves as a meander cutoff, with the river sinking into the ground, leaving part of the valley dry much of the year. Past courses of the river through the cave may be associated with the headward erosion of the valley. Some of these older cutoff routes are large tunnels that record periods of stable drainage alternating with periods of downcutting, and so far have remained undated. However, evidence from the sediments, speleothem dates, and cave morphology indicate that many of these passages were formed and subsequently filled with sediment prior to 160,000 years ago, the oldest speleothem dates obtained from Mystery Cave. During the last 160,000 years, the Root River has occupied portions of older passages and created new solution conduits at lower elevations. Older, upper-level passages are gradually being reopened as the sediment fill is excavated from below.

Other caves closer to the Mississippi River and well above the present water table contain speleothems that predate 350,000 years, as well as more recent material. Abandoned solution cavities and caves at different elevations combined with ages that range to >350,000 years reflect a history of water-table lowering, which must be related to regional processes such as downcutting by surface streams. Speleothems and sediments preserved in caves and solution cavities—materials not typically retained in the surface environment—may provide one means to date the time(s), rate(s) and effects of downcutting.

Innumerable questions may be asked concerning karst and regional geomorphic development during the Pleistocene. Was downcutting enhanced by plentiful water during periods of glacial meltback? How often and to what extent were valleys filled with glacial till and how did this affect drainage and downcutting? Where was the water table when ice covered the land surface, and did subglacial water, possibly under hydrostatic pressure, contribute to solution and erosion in the subsurface? How much erosion at the surface or solution in the subsurface would occur in a proglacial permafrost environment? Did most erosional and solutional activity occur when ice was absent or did it occur during transitional periods? These and related questions provide several topics for continued study and research into the processes that have created the present geomorphic landscape in the Upper Mississippi River valley.
OVERVIEW OF LANDSCAPE EVOLUTION IN NORTHEASTERN IOWA
I: PRE-WISCONSINAN

George R. Hallberg and E. Arthur Bettis III
Iowa Geological Survey

The distinctive terrain in northeastern Iowa and adjacent parts of Minnesota, Wisconsin, and Illinois has been referred to for many years as the "Driftless Area." The term had its origins in the early geologic interpretation of the region. The lack of recognition of glacial-drift deposits, and the high relief and extensive bedrock exposures in this area suggested that it had not been glaciated. The term "Driftless Area," however, should be discarded. It is incorrectly applied in Iowa to an area much larger than its original, geologically defined limits (Hallberg and others, 1984). And within those original boundaries, patchy remnants of glacial drift are well documented (Williams, 1923; Trowbridge, 1966).

As early as 1923 Williams (1923) recognized deposits of till and glacial erratics throughout the "Driftless Area" in Iowa. Trowbridge (1966) reviewed investigations in this region, documenting glacial deposits throughout the uplands in Iowa east to the Mississippi River, and north to the Minnesota border. Willman and Frye (1969) documented two tills in Iowa and glacial outwash on upland surfaces in the "Driftless Area" of Illinois. Most recently, Knox (1982) showed that pre-Illinoian till is present in the Wisconsin portion of the area, just east of the Mississippi River. While other portions of the "Driftless Area" in Wisconsin are apparently driftless (Knox, 1982), there is no driftless area in Iowa, and substantial portions of the region in Illinois contain glacial deposits as well. Hence, the term Paleozoic plateau seems a more fitting name for this physiographic province, particularly in Iowa (see Prior, 1976; Hallberg and others, 1984).

In the past these glacial deposits have been assigned to either "Kansan" or "Nebraskan" age (see Trowbridge, 1966). Recent work has rendered these glacial-stage terms obsolete, and the age of these deposits is now considered pre-Illinoian (Hallberg, 1980a). This area was glaciated repeatedly in the pre-Illinoian; tills of two major pre-Illinoian formations (the Wolf Creek and older Alburnett Formation) occur in the Paleozoic plateau area (e.g., Hallberg, 1980a, p. 101-102). The younger of these tills (Wolf Creek Formation) cannot be directly dated in northeastern Iowa, but in southwestern Iowa it is younger than 600,000 years, and its age may be estimated at about 500,000 years (Hallberg and Boellstorff, 1978; Lineback, 1979; Hallberg, 1980b). This provides an estimate for the age of the last glacial advance that covered northeastern Iowa.

Loess-mantled, pre-Illinoian glacial deposits dominate the surficial materials outside of the Paleozoic plateau in northeastern and east-central Iowa (see Ruhe, 1969; Prior, 1976; Hallberg, 1980a). The landscape developed on these deposits is dominated by multi-leveled, stepped, erosion surfaces cut prior to, and during Wisconsin loess deposition (Ruhe, 1969; Hallberg and others, 1978). These loess-mantled surfaces (where all are preserved), descending from oldest to youngest, from divides toward the valleys, are the Yarmouth-Sangamon, the late-Sangamon, and several
Wisconsinan-age, "Iowan" erosion surfaces. Indeed, this same model and sequence of erosion surfaces and paleosols can be discerned in the Paleozoic plateau region, although the greater topographic relief and steep slopes complicate the picture.

On the primary stream divides, 4 to 6 m of loess overlies well-drained paleosols developed on pre-Illinoian tills. The paleosols are generally 1 to 2 m thick, but locally may be thicker (2-5 m). These paleosol thicknesses, as well as other features, are typical of late Sangamon paleosols, not the Yarmouth-Sangamon, and these characteristics suggest that the late Sangamon erosion surface has cut across the entire landscape. Only in local areas are remnants of the older Yarmouth-Sangamon paleosols preserved on the divides. The late Sangamon erosion surfaces form pediments which grade toward the present valleys, indicating that the present drainage was established by "late Sangamon time." The late Sangamon paleosol and erosion surface may truncate the pre-Illinoian till and descend onto the Paleozoic bedrock. On carbonate rocks in the area, the reddish, clay-rich B-horizon of the paleosol has often been called residuum or "terra rossa," supposedly derived from weathering of the underlying rock over long periods of time. In most areas in Iowa, however, this "residuum" contains erratic pebbles derived from the glacial deposits. The mineralogy and chemistry of these "red clays" generally bear little resemblance to the bedrock, but are similar to the eroded Pleistocene deposits.

The "late Sangamon" erosion surfaces and associated valley alluvium sit high above the principal modern stream valleys. Younger (Wisconsinan) erosion surfaces and fluvial deposits are inset below the late Sangamon pediments and alluvium. This evidence indicates that the main entrenchment of the present landscape took place after "late Sangamon" time.

Additional insights into the landscape evolution of the Paleozoic plateau region are provided by careful observation of the relationship between the karst, pre-Illinoian glacial deposits, and the present surface-drainage features. Subsurface karst conduits are linked to the history of dissection in the region because karst solutional activity generally takes place at, or just above, the piezometric surface in a carbonate aquifer (Thrailkill, 1968; LeGrand and Stringfield, 1973; White, 1977). The karst-carbonate aquifers discharge to the major stream valleys, such as the Mississippi, Turkey, Yellow, and Upper Iowa Rivers. Thus, the depth of dissection of these valleys acts as a base level for the piezometric surface in these aquifers, and controls the depth of solutional conduit development. As the piezometric surface lowers in response to entrenchment of the master streams, karst development can proceed to greater depths, and higher (older) conduits or caves pass into a vadose or partially air-filled (unsaturated) state. In a vadose condition, secondary carbonate deposits, or speleothems (stalactites, stalagmites, and flowstone), can begin to form. Various aspects of the karst system are thus related to the landscape evolution of the region.

Bounk (1983) concluded that most of the karst caves in northeastern Iowa have formed since the last glaciation of the region. The caves examined are related to the present topographic-hydraulic gradient, and thus formed after the present drainage network became established. Only a few
of the highest level (oldest) caves were not in adjustment with the configuration of the modern drainage system. Bounk (1983) interpreted these to have formed immediately after the last glaciation, before (and during) establishment of the present drainage network. In addition, nowhere in northeastern Iowa have we found karst features where pre-Illinoian glacial deposits were directly deposited in the karst. This is in contrast to karst on Mesozoic gypsum beds in central Iowa where pre-Illinoian tills were clearly deposited into, and fill the karst surface.

Speleothem deposits can be radiometrically dated by uranium-series methods. Because speleothems develop only after conduits are in a vadose state, dates on the speleothems provide minimum ages on major valley down-cutting. Growth of speleothems is episodic and, in part, climatically controlled (Lively and others, 1981). Lively (1980, 1983; Lively and others, 1981) of the Minnesota Geological Survey has compiled over 50 dates from various caves in Minnesota and Iowa. A few samples have dated between 250,000 and >350,000 years; some of these dates were from samples of vein calcite which may relate to much older diagenesis and mineralization (Ludvigson and others, 1983). The remaining dates fall into three age groups: 163,000 to 100,000; 60,000 to 35,000; and from 15,000 to present (also see Part II: Wisconsinan, this volume).

The geologic evidence from stream valleys, like that from uplands and karst features, must be analyzed to understand landscape evolution in the Paleozoic plateau. The oldest known valley feature preserved in the area is the Bridgeport terrace, located in the lower reaches of the Wisconsin River valley. This terrace surface is about 45 to 50 m above the adjacent Wisconsin River floodplain, and approximately 30 m higher than the (presumed) late Wisconsinan terrace on which the town of Prairie du Chien is built (Knox, 1982). The Bridgeport terrace is actually an intra-Pleistocene bedrock strath cut into Prairie du Chien Group dolomite and sandstone (Knox and others, 1982). Till, correlated with Wolf Creek Formation tills present on uplands on the Iowa side of the Mississippi, occurs on the strath near the mouth of the Wisconsin River. Fluvial deposits, interpreted as outwash associated with this till, extend up the present Wisconsin valley, thinning and fining to the east (Knox and others, 1982). The reversed gradient on the outwash and the fact that it fines in an eastward direction suggest that the ancestral Wisconsin River flowed eastward when this pre-Illinoian glacier advanced into the area. High-level benches cut into rock, just slightly lower than upland landscape positions, are present in upper portions of the Kickapoo River valley, a major south-flowing tributary to the Wisconsin River. These benches are capped by alluvium in which a paleosol has developed. The alluvium and paleosol are, in turn, buried by Wisconsinan colluvium and loess (Knox and others, 1982). These benches may grade to and therefore may be roughly equivalent in age to the Bridgeport terrace (Knox, 1982). Equivalent deposits have not been recognized in northeastern Iowa, and no "valley" surfaces as prominent or as old as the Bridgeport are known from anywhere else along the Upper Mississippi valley. The deeper entrenchment and alignment of the modern valleys are subsequent to events which created the Bridgeport terrace and associated high-level benches.

The completion of this overview, will be outlined in Part II: Wisconsinan (this volume), which summarizes important, younger facets of
the Quaternary history. In sum, evidence provided by the pre-Wisconsinan Quaternary history of northeastern Iowa collectively suggests that most of the modern drainage network and karst features have evolved since the last pre-Illinoian glacial event in the region.

OVERVIEW OF LANDSCAPE EVOLUTION IN NORTHEASTERN IOWA
II: WISCONSINAN

George R. Hallberg and E. Arthur Bettis III
Iowa Geological Survey

The discussion of the geologic evidence of the Wisconsinan history of this region will parallel Part I: pre-Wisconsinan. An outline of observations from the upland stratigraphy, karst features, and stream valleys will be summarized.

Stream erosion and hillslope development since the last glacial event have produced a deeply dissected landscape, and in the process also removed the glacial deposits in most areas from all but the highest divides. In addition, upland surfaces are mantled with 3 to 6 m of late Wisconsinan loess. Organic carbon from the base of the loess, near Garnavillo in Clayton County, was dated at 25,300 ± 650 RCYBP (ISGS-512; Hallberg and others, 1978). The end of loess deposition in Iowa is generally considered to be about 14,000 years ago (Ruhe, 1969). The loess cover commonly obscures the older glacial deposits; however, relationships among the loess, pre-Wisconsinan buried soils, and erosion surfaces provide further insights into the evolution of this landscape.
Inset below the late Sangamon surfaces are younger, Wisconsinan-age, "Iowan" erosion surfaces which vary in number. The "Iowan" surfaces typically are cut into rock, have no paleosol developed into them, and are buried by a thinner increment of loess. The surfaces, which stabilized and were buried by loess between 20,000 and 17,000 years ago, commonly stand 35 to 55 m above the major streams (e.g., Turkey River) and 10 to 30 m above smaller streams. Where an individual erosion surface is bordered by steep slopes and high relief (15 to 20 m or greater), the loess and rock grade laterally off the shoulder of the slope into a steep colluvial slope deposit composed of a mixture of loess and large angular boulders of the local bedrock. These slope deposits grade into, or are truncated by, even younger fluvial deposits in the valley below.

As noted in Part I, most of the karst features in the region relate to this geologically young landscape, and the majority of U-Th dates of speleothems are Wisconsinan in age. Other aspects of cave development along the Silurian Escarpment adjacent to the Turkey River and its tributaries reveal features directly related to the history of the valleys. These caves generally underlie subtle, minor, surface valleys. The caves and valleys emerge from the Silurian Escarpment into small, narrow gorges which are filled with large, angular, blocky talus. These gorges mark collapsed sections of former cavern systems (Hedges, 1967). The talus grades into a colluvial mixture of loess and bedrock blocks mantling the steep slopes of the region. The colluvium is related to the late-Wisconsinan erosion surfaces on the upland. At Dutton's Cave, Fayette County (Hedges, 1967), and at other localities observed by the authors, the talus descends to, and interfingers with, high-level, loess-mantled terrace deposits.

In valleys of major streams, high-level, bedrock-cored, cutoff meanders are inset below the "late Sangamon" and older alluvium and erosion surfaces. These bedrock-cored meanders are present in all the major valleys, except the Mississippi. Drill-hole data from Wisconsin (Knox, 1982) and Iowa show that the rock-cored meanders are filled with a very thick sequence (25-35 m) of deposits, with sand and/or gravel at the base, extending to depths of 10 to 20 m below the present floodplain level. The surface of the sediments filling these meanders usually stands 20 to 25 m above the present floodplain. The surfaces of these meanders increase in elevation above the modern floodplain in a down-valley direction, suggesting that the present valley gradient is steeper than when the river flowed through the rock-cored meanders. This relationship is complicated by deposition of local alluvium, colluvium, and eolian materials on the original surface of the fluvial deposits.

Earlier work has offered several different opinions on the age of these meanders and related high terraces. Calvin (1894, 1906) concluded that these "high gravelly terraces" were "Kansan" in age, "deposited by floods from the melting Kansan ice..." (Calvin, 1906, p. 124). In contrast, Leonard (1906) considered their age uncertain but suggested they might be Wisconsinan. More recently, Knox (1982, p. 12-14) inferred a post-"Kansan" to early Illinoian age.

Recent investigations in Iowa have dated these terraces as Wisconsinan. Loess-mantled, late Sangamon surfaces on the upland sit high above the pres-
ent valleys and are graded to valley levels much higher than those of the bedrock-cored meanders, perhaps to positions similar to the high-level benches in Wisconsin. Moreover, the bedrock-cored meanders are inset below the late Wisconsinan ("Iowan") erosion surfaces. As noted above, these loess-mantled, late Wisconsinan surfaces grade laterally, on the shoulders and backslopes, into steep slopes mantled with colluvium or talus in a silty matrix. The silty matrix was derived from late Wisconsinan loess which accumulated during development of the colluvial aprons. These colluvial aprons grade into rubble associated with the collapse of abandoned karst conduits. In a section near Elkader, in Clayton County (Fig. 1), these colluvial deposits can be traced down the slope and beneath the fluvial deposits which fill a now abandoned bedrock-cored meander of the Turkey River. Spruce wood in the colluvium, about 15 m below the surface of the terrace and 2 to 5 m above the bedrock floor of the meander, was radiocarbon dated at 20,530 ± 130 years (Beta-2748). The colluvium flanks the valley wall of the meander and passes under fluvial deposits filling the meander. The colluvium also interfingers with fluvial deposits, cross-bedded sands and gravels, in the abandoned meander.

In Grant County, Wisconsin, organic sediments, from near the base of similar colluvial and fluvial sediments along the side of the valley, were dated by Knox (1982, p. 3) at 20,270 ± 650 years (ISGS-558). In Vernon County, Wisconsin, peat occurring about 4 to 5 m above the bedrock and 12 to 13 m below the land surface in a similar colluvial deposit, has been dated at about 29,600 years (Knox, 1982, p. 37; pers. commun.). Furthermore, drill cores within Citron Valley (Fig. 1), a large, correlative, bedrock-cored cutoff meander, revealed organic-rich sediments at the top of the fluvial deposits which fill the base of the valley. The organic sediment was about 22 m below the surface of the terrace, and about 8 m above the bedrock floor. The sample was dated at 21,910 ± 350 RCYBP (Beta-4808). Prior to C-14 dating, these deposits were interpreted as pre-Wisconsinan, possibly as old as "Kansan" (whatever that is?) (Knox, 1982).

The talus and colluvium which descend into the alluvial fills in these high-level, meander terraces are clearly late-Wisconsinan in age. Because late-Wisconsinan colluvium lines the valley walls and partially fills the bedrock-cored meanders, entrenchment of the meanders predates these deposits. On the basis of present information, the entrenchment can only be estimated at some time prior to about 30,000 years ago. The dates already cited from deep within these valley fills, and the intimate association of colluvial rubble with the bedrock walls, suggest that most of the entrenchment probably occurred in the middle to late Wisconsinan.

There is no precise date for the age of the cutoff and abandonment of the rock-cored meanders. Fluvial deposition was occurring actively in these meanders about 20,000 years ago, as already noted. From 10 to 20 m or more of sediment were deposited in the meanders after 20,000 years ago. After valleys had aggraded to this level, the rivers began to downcut again, abandoning the bedrock-cored meanders, producing the present valley configuration which has a much straighter and steeper alignment. The best estimate at present suggests that these surfaces were stabilized and then abandoned near the end of the period of loess deposition about 17,000 to
Figure 1. Cross sections showing stratigraphy and dated horizons in two bedrock-cored cutoff meanders: A, Elkader section along the Turkey River in Iowa; B, Citron Valley (after Knox, 1982) showing Knox's interpretation and our reinterpretation following C-14 dating. Abbreviations: OG, Ordovician Galena Group. PIT, Pre-Illinoian till. LSP, late Sangamon paleosol. FW, pre-Woodfordian; f, fluvial deposits; s, silt. W, Wisconsinan; c, colluvium; f, fluvial deposits; 1, loess; Ld, loess-derived alluvium; la, local alluvium; af, alluvial fan deposits. BLP, basal loess sediments and paleosol. H, Holocene; a, alluvium; s, silt.
14,000 years ago. The Savanna (Zwingle) "red-clay" terraces are clearly inset below the bedrock-cored meanders, also supporting this age for abandonment (see Bettis and Hallberg, this volume).

There are many examples in the literature of "mistaken antiquity" assigned to valley features in this area of the midwest, simply because the valleys are cut into bedrock. Another example is Couler Valley, a distinctive and unique abandoned valley of the Little Maquoketa River (Prior and Heathcote, 1978). Trowbridge (1954) referred to Couler Valley as "Kansan" in age, and correlated it with the Bridgeport strath. However, Savanna terraces occur within Couler Valley and near its mouth at Sageville. Most of Couler Valley is cut below these Savanna terraces, and thus must be younger, probably Holocene in age. In fact, in historic times, Couler Valley has taken overflow from the Little Maquoketa (Calvin and Bain, 1900, p. 392). Ongoing investigations are disproving the great antiquity formerly assigned to these features, and point out how remarkably young much of the landscape is.

These relative age relationships can be pushed a little further. A few high, sandy terraces are present in the Mississippi valley, inset below the Savanna terraces, but 12 to 15 m above known Holocene terraces (the towns of Harpers Ferry and Prairie du Chien are built on these terraces) and thus the terraces must be latest Wisconsinan to earliest Holocene in age. (Some aspects of the Holocene history are reviewed by Bettis and Hallberg, this volume.)

Evidence from studies of the upland stratigraphy and erosional history, the development of the karst system, and the fluvial deposits in the stream valleys are beginning to reveal a coherent picture of the Pleistocene history of the Upper Mississippi valley region. A few key points to emphasize are: (1) The Mississippi River and its tributaries evolved within the middle Pleistocene, probably after the last glaciation to cover northeastern Iowa about 500,000 years ago; (2) the drainage network was established by "late Sangamon" time, but major stream incision probably began about 160,000 years ago; (3) the major period of valley downcutting was in the Wisconsinan, and formed the prominent bedrock-cored cutoff meanders; (4) as these deep valleys were aggrading about 20,000 years ago, periglacial activity formed prominent colluvial slopes, and vadose karst conduits collapsed, leaving a mantle of bedrock-derived rubble within a loessal matrix on steep slopes and in related valleys; and (5) the stream valleys underwent a complex history of erosion and aggradation between 17,000 and 10,000 years ago in response to changes in glacial drainage in the Mississippi River basin. As further work is done on the complex evolution of this landscape, the valley history must be tied in with other studies of the Mississippi River to the south (e.g., Anderson, 1968), and with the continuing question of whether or not isostatic uplift has played any role in the deep incision of the streams into the bedrock (Trowbridge, 1921; Willman and Frye, 1970).

Early workers suggested that many of the landscape features in this region, such as the various high-level terraces, were very old. However, modern investigations of these features show that they are geologically quite young, generally Wisconsinan or even Holocene in age.

40
THE SAVANNA (ZWINGLE) TERRACE AND "RED CLAYS" IN THE UPPER MISSISSIPPI RIVER VALLEY: STRATIGRAPHY AND CHRONOLOGY

E. Arthur Bettis III and G.R. Hallberg
Iowa Geological Survey

The Savanna terrace is a distinct physiographic feature along tributaries to the Upper Mississippi River valley (UMV). The surface of the terrace stands about 20 m above the modern stream level in northeastern Iowa and decreases in elevation, relative to present stream level, down the UMV, until it is only a few meters above stream level in central Illinois. The terrace exhibits a flat to slightly reversed gradient within tributary valleys and extends less than 8 km up these valleys.

Numerous workers have noted that the Savanna terrace is the highest terrace in the UMV area without a loess cover and thus stabilized after about 14,000 to 12,000 RCYBP. The distinctive and most studied feature of the terrace is the alternating red and gray "clays" which dominate the upper part of the deposits in the terrace section. Mineralogic studies suggest different northern sources for the two sediments. The gray silty clay is dominated by montmorillonite with some illite and kaolinite. The red clay contains much more chlorite and kaolinite than the gray silty clay. The difference has been interpreted as reflecting a "Lake Agassiz" source for the gray silty clay and a "Lake Superior" source for the red clay (Flock, 1983). The terrace deposits are inferred to have accumulated as slackwater and backflood deposits produced by high-magnitude floods on the Mississippi River resulting from catastrophic lake drainage in the UMV (Madenford, 1974; Clayton, 1983).

In northeastern Iowa the Savanna terrace is composed of two zones having distinct sedimentary structures and lithology. The upper zone consists of dominantly planar bedded, gray silty clay, yellowish-brown silt, and red clay. Occasionally, thin beds of fine sand are found in this zone. Individual beds range from a few centimeters to about 50 cm in thickness. Occasional beds composed of "clay" rip-up clasts are present within this zone, and massive or laminated red clay beds are abundant. This zone is all that is typically noted in the literature. The underlying zone consists of planar bedded, gray silty clay and yellowish-brown silt with infrequent or no red clay beds. Individual beds are thicker in this zone than in the upper zone and typically range from 20 to 100 cm in thickness. Broad, shallow troughs filled with fine to medium sand and/or rip-up clasts of red clay and gray silty clay are common in this zone. Beds of fine to medium sand are also present within the lower zone. The lower zone extends an unknown distance below the present creek or river level in northeastern Iowa valleys. Thus, the total thickness of the sediment package and the properties of the basal deposits are unknown at this time.

Deposits making up the Savanna terrace truncate colluvial slope deposits along the valley margins. Several C-14 dates from northeastern Iowa and southwestern Wisconsin in conjunction with stratigraphic relationships indicate that these colluvial slopes developed between about 30,000 and 20,000 RCYBP. Flock (1983) correlated the Savanna terrace with the Deer Plain terrace in the lower Illinois River valley. Several dates from the
base of the Deer Plain terrace indicate that it began accumulating around 13,300 years ago. On the basis of this correlation, Flock suggested the age of the basal Savanna Terrace deposits would be around 13,500 RCYBP. This age fits well within the chronology of glacial lake drainage into the UMV proposed by Clayton (1982, 1983). That chronology is based, in part, on C-14 dating of shoreline and delta features associated with glacial lakes Superior and Agassiz and extrapolation of those dates to water planes and the elevation of outlets. Their chronology suggests that significant glacial lake drainage into the UMV spanned the period from about 12,300 to 9,500 RCYBP.

Recent radiocarbon dates on wood and organics within Savanna terrace deposits raise serious questions as to the validity of the basal age assigned to the Savanna terrace by Flock. Three dates from Allamakee and Clayton counties in northeastern Iowa all predate those from the Deer Plain terrace. The dates (17,700 ± 310 RCYBP--Beta-7403; 16,470 ± 560--Beta-7404; 13,730 ± 320 RCYBP--Beta-7980) indicate that the Savanna terrace was accumulating prior to the proposed draining of glacial lakes Superior and Agassiz. These dates were collected from within the terrace deposits and do not date the commencement of terrace sedimentation.

Additional dates, stratigraphic relationships, and archeological data also shed light on the termination of Savanna terrace accumulation. Near the mouth of Catfish Creek south of Dubuque, Iowa, a sand-mantled terrace is inset 2-3 m below Savanna terrace remnants. Deposits making up the younger terrace consist of stratified, gray, montmorillonitic, silty clay and fine to medium sand. Red clay rip-up clasts are occasionally encountered, but no continuous red clay beds are present. Wood collected from within these deposits at a depth of 9.5 m dated 12,600 ± 180 RCYBP (Beta-4979) while wood collected from a depth of 7.6 m dated 11,150 ± 110 RCYBP (Beta-4978) (Hallberg and others, 1984). The stratigraphic relationships between this terrace and the Savanna terrace, combined with the radiocarbon dates from within the lower terrace, indicate that in this region accumulation of the Savanna terrace had ceased by 12,660 RCYBP at the latest.

A radiocarbon date of 7,040 ± 170 RCYBP (Beta-7981) was obtained from secondary carbonates collected 5 to 6.7 m below the surface of a Savanna terrace near the mouth of the Turkey River in Clayton County, Iowa. This indicates that by that date the terrace deposits were in place and had been leached long enough for the secondary carbonates to have accumulated.

Recent archeological investigations by Mallam at the Aulwes Site, located on a Savanna terrace in Buck Creek, Clayton County, Iowa, have shown that prehistoric use of the terrace surface occurred 7,000 to 8,000 years ago (Mallam, pers. commun.). Obviously, tributary streams were cut deeply into Savanna terrace deposits by that time.

Farther to the south both older and younger deposits of "Superior" red clays occur. In the Goose Lake Channel area (Clinton and Jackson Counties, Iowa) such red clays occur in Wisconsinan fluvial deposits, which are buried by loess and thus are ca. 17,000 to 25,000 RCYBP. Very thin layers of red clay, which may be related, occur within "loess" in the bluffs of the UMV (St. Clair County, Illinois; McKay, 1979, p. 61-63). These clay
layers lie below a date of 16,020 RCYBP and are thought to represent "a high water level in the Mississippi valley associated with the diversion of the Mississippi River, about 20,200 radiocarbon years B.P." (ibid., 1979, p. 62).

In the areas of Clinton County, Iowa, and Whiteside County, Illinois, other dated sequences define younger red clay occurrences. Here the red clays of the Savanna terrace occur 12 m above the Mississippi River bottomland. Inset below the terrace deposits, younger red clays occur within a sequence of Holocene peat and gray slackwater clays in the Cattail Channel area; these red clays lie slightly above a C-14 date of 10,130 ± 90 RCYBP (Beta-4536) and 1.5 m below a date of 8,860 ± 80 RCYBP (Beta-4537). Thin units of similar red clays and silts occur within even younger Holocene alluvium in the UMV and adjacent valleys that Mississippi River floodwaters carry into. An additional complicating factor is the possibility (or probability) of beds of reworked red clay in Holocene deposits in the UMV and its tributaries. These various occurrences make use of the red clays as minimum-age markers, as practiced by Church (1984), wholly untenable.

Red "Superior source" clays occur in many stratigraphic positions, ranging from mid-Wisconsinan to late Holocene, in the UMV and the downstream reaches of its tributaries. Many of these deposits are primary, but a distinct possibility exists that some are reworked. The deposits comprising the Savanna terrace developed over a significant portion of the late Wisconsinan probably between 20,000 and about 12,500 RCYBP. Zonation of the Savanna terrace stratigraphy and various sedimentary structures suggest that flow and/or sediment-supply conditions varied during accumulation of the deposits. The age of the base of the terraces may change down the Mississippi valley. The chronology of these deposits does not readily fit the model proposed by Clayton (1982, 1983).
Roberts Creek is a major left-bank tributary of the Turkey River in Clayton County, Iowa. Roberts Creek's basin encompasses 350 km² of the Paleozoic plateau landform region (Prior, 1976; Hallberg and others, 1984). Carbonate bedrock of Ordovician age crops out extensively in the basin and is generally within 10 to 15 m of the surface on divides where Quaternary deposits are thickest. An extensive karst network (including sinkholes, blind valleys, springs, and caves) is developed in the bedrock and in many areas exerts a strong influence on surface topography and stream flow.

Upland stratigraphy within the basin is typical of the Paleozoic plateau area. Patchy, eroded remnants of pre-Illinoian till (largely Wolf Creek Formation) are present overlying fractured but otherwise relatively unweathered carbonate bedrock. On the most stable paleolandcape position, late Sangamon paleosols are developed into the eroded till surface. These paleosols descend onto adjacent rock surfaces which are significantly more karstified (weathered) than adjacent rock buried beneath till. The ancient surface, across which late Sangamon paleosols are developed, is the late Sangamon erosion surface (Ruhe, 1969; Hallberg and others, 1984). This erosion surface descends toward modern drainageways such as Roberts Creek, but it is not graded to the present valleys; it is graded to a level high above Holocene and Wisconsinan valley surfaces. This suggests that the present major drainage lines were established by "late Sangamon" time, but that the drainage network was not as deeply entrenched into the bedrock and pre-Illinoian deposits as it is today. Extensive Wisconsinan erosion surfaces are cut into the late Sangamon erosion surface on the upland. Erosion during development of these surfaces removed all, or portions of, the late Sangamon paleosol, and commonly all the pre-Illinoian deposits. The late Sangamon and occasionally the Wisconsinan erosion surfaces are buried by Basal Loess Sediment with the Basal Loess Paleosol developed into them. These deposits and paleosols are in turn buried by late Wisconsinan (Peoria) loess. Generally the late Wisconsinan loess lies directly on a Wisconsinan erosion surface with no intervening paleosol or Basal Loess Sediment.

Extensive loess-mantled bedrock benches are cut below the late Sangamon and Wisconsinan erosion surfaces along Roberts Creek. On these benches as much as 3 m of calcareous sandy and gravelly alluvium buries unweathered bedrock. The alluvium grades upward into the overlying mantle of late Wisconsinan (Peoria) loess with no intervening paleosol or erosion surface. From the stratigraphic evidence the age of the benches can thus be bracketed as younger than the late Sangamon erosion surface and paleosol; older than the end of regional loess deposition (ca. 14,000 to 12,000 RCYBP); and younger than or contemporaneous with development of the Basal Loess Paleosol in eastern Iowa, which developed between 27,000 and 21,000 RCYBP (Hallberg and others, 1978, 1984). Therefore the loess-mantled benches in this area are late to middle Wisconsinan (Woodfordian?) in age. This correlation is supported by the fact that the bedrock bench surfaces
grade down Roberts Creek to the rock surface in abandoned rock-cored meanders in the Turkey River valley. The age of these rock-cored meanders has also been established as late to middle Wisconsinan (Woodfordian) (Hallberg and others, 1984; Hallberg and Bettis, this volume).

A complex suite of late Wisconsinan (<15,000 RCYBP) and Holocene (<10,500 RCYBP) alluvial deposits is inset several meters below the rock surface of the loess-mantled bedrock benches. These deposits have been extensively radiocarbon dated and lithologically are very similar to deposits in southwestern Wisconsin described by Knox and others (1981) and McDowell (1983). These alluvial fills can be placed into three broad groups differentiated on the basis of lithologic, pedogenic, and geomorphic properties. The first group consists of massive to weakly stratified silty and/or loamy alluvium. A-B-C soil horizon sequences have developed into it. B and C horizon colors of soils developed into this alluvium are moderately high in value and chroma (10YR and 2.5Y 4/3-5/4). This group is latest Wisconsinan to late middle Holocene in age (15,000 to 4,000 RCYBP). The second alluvial fill complex is characterized by massive to weakly stratified loamy alluvium. Only A-C soil horizon sequences have developed into it. Colors below the solum in this complex have low value and chroma (10YR-2.5Y 2/1-3/2). These fills accumulated between about 3,500 and 300 RCYBP and occur in a belt paralleling the modern channel. The third group of deposits is composed of stratified silty and loamy alluvium. No soil development is present and the deposits characteristically exhibit moderately high value and chroma colors. This unit buries much of the present floodplain and low terrace surfaces and commonly contains historic debris.

In summary, five major points concerning Quaternary valley evolution in the Paleozoic plateau of the Upper Mississippi River basin are demonstrated in the Roberts Creek area: (1) Landscape evolution in the Paleozoic plateau region of northeastern Iowa and the Driftless Area of southeastern Wisconsin has been episodic. (2) Major drainage lines were developed by "late Sangamon" time, although the valleys were not entrenched deeply into the bedrock at that time. (3) Major entrenchment into the bedrock and development of prominent loess-mantled bedrock benches occurred during middle to late Wisconsinan (Woodfordian?) time. Similar stratigraphic and geomorphic relationships exist in southwestern Wisconsin (Knox, 1982; Hallberg and others, 1984). (4) A sequence of latest Wisconsinan and Holocene alluvial deposits is cut below the Woodfordian loess-mantled benches. Similar deposits are also present in southwestern Wisconsin (Knox and others, 1981; McDowell, 1983). (5) Thus, similar events and resulting sequences of similar deposits mark landscape evolution in the Paleozoic plateau and in the Driftless Area.
SURFICIAL DEPOSITS ON THE PALEOZOIC SURFACE IN SOUTHEASTERN MINNESOTA:
THEIR DISTRIBUTION AND GEOMORPHIC RELATIONSHIPS

Robert Lueth
U.S. Department of Agriculture, Soil Conservation Service
Lewiston, Minnesota

The Paleozoic bedrock surface in southeastern Minnesota is mantled with a diverse range of materials. These consist of upland ridge deposits that include thick terra rossa, stratified sediments, glacial till, and glacial outwash; rocky colluvium on interfluve flanks; silty, sandy, and clayey sediments on terraces; and Holocene deposits on floodplains.

Upland Deposits

The oldest material lying on the upland bedrock surface in southeastern Minnesota is cherty clay terra rossa and a stratified sandy to clayey sediment having a component of New Richmond Sandstone. These sediments are 1 to 17 m or more in thickness in eastern Winona and Fillmore Counties and in all of Houston County. Mineralogically the sediments are unrelated to the underlying bedrock. The stratified sediments approximate the position formerly occupied by the New Richmond Sandstone, of which only remnants remain.

In western Winona County, the Prairie du Chien surface is covered by less than a meter of terra rossa and by less than 2 m of stratified sandy and clayey sediments. The New Richmond Sandstone is largely intact in this region.

Loess-covered, patchy pre-Illinoian till and outwash lie on the terra rossa and stratified materials in western Winona County. The till is 2 to 7 m thick, and the outwash is typically less than 2 m thick. In one township-sized area of west-central Winona County both the till and outwash lack the loess cover, although the till is indistinguishable from the nearby loess-covered till. The loess-free drift deposits overlie thin remnants of the lower part of the St. Peter Sandstone, a stratified sandy and clayey residuum-like material. In places a cherty clay lies below the drift.

In the other parts of Winona and Houston Counties loess covers the upland surface and the footslopes at the base of steep valley walls. The loess cover is up to 20 feet thick on upland divides in western Winona and Houston Counties and thins eastward. Loess thickness is also related to the slope aspect, the interfluve width, and the degree of protection by nearby upwind interfluves.

The loess mantle, in places of western Winona County, is composed of at least two increments of loess. The upper layer of loess is less than 1 to 2 m thick, and is distinctly finer in texture than the lower layer. The two-storied loess extends westward to the Iowan erosional surface in Olmsted County.

A few elliptical knolls exist around the border of the loess-free drift in western Winona County. These knolls are composed of a loess that is distinctly coarser in texture than the loess in the rest of the region.
Valleys and Terraces

In places along the Mississippi River, sandy, late Wisconsinan alluvium composes terraces or thinly mantles small strath terraces. Sandy alluvium of earlier origin also occupies terraces on the Root River in Houston County. These terraces extend into the eastern part of Fillmore County. Sandy alluvium also forms terraces on the lower reaches of streams in the western part of Winona County.

Upstream on most of the rivers mapped, the sandy alluvium merges with silty alluvium. The upper part of the silty alluvium is similar in composition and texture to the loess on the surrounding uplands. The lower part consists of stratified silty and sandy sediments, dominated by fine and very fine sand sizes.

Red and gray slackwater clays occupy terraces at the mouths of streams tributary to the Mississippi River.

Observation on the Evolution of the Upland Surface

The terra rossa and stratified sediments appear to have been transported. The stratified sediment that drapes the terra rossa in many places has slumped downslope from the position formerly occupied by the New Richmond Sandstone, from which the stratified sediment is at least partially derived.

Observations on the Upland Landscape

Interfluves on the Paleozoic upland have stepped surfaces. Differential erosion has lowered summits near the ends of interfluves by stripping away stratified, sandy to clayey sediments and exposing cherty clay terra rossa. Glacial till was no doubt removed also. Loess deposits have also been differentially removed to some extent. Erosion has been most intense and the loess is thinnest in saddles created by drains that are cutting into both sides of narrow interfluves.
Glaciers advanced into Barron County at least seven times during the Pleistocene. During the earliest known advance, olive-black loam till of the Pierce Formation was deposited in the western part of the county by an ice lobe from the west. This advance occurred probably several hundred thousand years ago. After development of a thick weathered zone in the Pierce till, yellowish-red sandy loam till of the River Falls Formation was deposited throughout the county by advances of the Superior and Chippewa lobes. Weathered magnetite and clay minerals indicate that the till was weathered for a long time following these advances. These advances probably occurred before the Wisconsinan Glaciation.

Four advances occurred during the last part of the Wisconsinan Glaciation. The yellowish-red sandy loam till deposited during these advances is included in the Copper Falls Formation. Copper Falls till was deposited first during an advance of the Chippewa lobe into the eastern part of Barron County, followed by an advance of the Superior lobe into the western part of the county. Finally, the Superior and Chippewa lobes advanced at the same time, depositing Copper Falls till and forming the St. Croix and Chippewa moraines. No moraines mark the extent of the two earlier late Wisconsinan advances. Buried ice left from these two advances did not melt until after the final two advances, suggesting that only a short period of time separated these advances.

The Copper Falls till and River Falls till are similar in color and texture but can be distinguished on the basis of clay mineralogy and magnetic susceptibility. These two characteristics differ between the two formations because of the greater amount of weathering that has occurred in the River Falls till.

The glacial history preserved in Barron County affirms and supports previously reported chronologies in the region and indicates when glaciers covered the Upper Mississippi valley basin. An abrupt change in the character of the younger Superior lobe deposits suggests a change in ice-flow character at the end of the Wisconsinan glaciation and may imply similar changes in the discharge of meltwater.
The lower Illinois River, a tributary to the Mississippi River in west-central Illinois, has one of the lowest gradients of major river valleys in the world (about 2.4 cm/km). The impounding effect of Mississippi River floods on the lower Illinois valley has long been recognized (Cooley, 1914; Rubey, 1952). At the turn of the century, the lower Illinois valley was a series of shallow backwater lakes, and detailed topographic maps show Illinois valley flood basins as much as 2 m lower than flood basins in the immediately adjacent Mississippi valley (Woermann, 1902).

Ongoing stratigraphic, geomorphic, and sedimentologic investigations in the lower Illinois valley indicate that the lower Illinois valley was affected by Mississippi River fluctuations during the terminal Pleistocene as well (e.g., Hajic, 1985a). In the lower 120 km of the Illinois valley the valley fill that is younger than about 14,500 RCYBP, consists of lacustrine and slackwater deposits and most geomorphic surfaces exhibit low or reverse slopes indicating that the lower Illinois valley repeatedly functioned as a settling basin. The age of the deposits and the morphology of associated terraces in the lower Illinois valley can be used to estimate the time and direction of Mississippi River fluctuations. Mississippi floods or valley aggradation and stabilization at high levels cause slackwater or lacustrine conditions in the Illinois valley. Conversely, with Mississippi valley degradation, fluvial activity will be renewed in the lower Illinois valley.

The lake that periodically formed in the lower Illinois valley is here referred to as Lake Calhoun. At least two terminal Pleistocene phases of Lake Calhoun, with associated terraces interpreted as exposed lake plains, can be identified and temporally bracketed.

The Deer Plain terrace in both the Mississippi and adjacent Illinois valleys (Rubey, 1952) is locally the highest terrace lacking a loess mantle. Rubey recognized the terrace and associated deposits as recording a period of Mississippi valley aggradation and consequent lake formation in the Illinois valley. Butzer (1977, p. 18) suggested that the marked reverse slope of the terrace in the Illinois valley may have developed "during successively lower stages of river level".

There are two segments to the Deer Plain terrace. (1) In the Mississippi valley and for several kilometers up the Illinois valley, cross-bedded sand and gravel is overlain by up to 4 m of interstratified silt, montmorillonitic, olive to gray silty clay, and reddish-brown clay relatively high in chlorite and kaolinite. Bedding in the sand was noted by Rubey (1952) to dip upvalley in the Illinois valley mouth. Small dunes sporadically cover the surface at the mouth of the Illinois valley. (2) In the Illinois valley, the Deer Plain surface is nearly featureless and slopes upvalley. It is underlain by laminated olive to gray montmoril-
lomitic clay, sometimes in excess of 14 m thick, with occasional reddish-brown clay interbeds in the lowest part of the clay. Olive clay is underlain by up to several meters of laminated gray silt with many interstratified reddish-brown clay laminae and beds usually over sand. The reddish-brown clay has been traced at depth in the Illinois valley subsurface southward to the solum of surface soils on the Deer Plain terrace at the mouth of the Illinois valley and into the Mississippi valley. Lithofacies associations and stratigraphic relationships between Deer Plain-related deposits confirm Rubey's model of sediment dam construction (first Deer Plain segment) and Illinois valley lacustrine deposition (second Deer Plain segment).

Wood collected in the lower Illinois valley from the basal laminated gray silt unit in direct association with reddish-brown clay dated $13,390 \pm 190$ RCYBP (ISGS-894), $13,010 \pm 140$ RCYBP (ISGS-900) (Hajic, 1985a), and $13,360 \pm 100$ RCYBP (ISGS-875) (Wiant and others, 1983; Hajic, unpublished data). In addition, wood from laminated silt in a broad sluiceway preserved in the uppermost segment of the lower Illinois valley yielded dates of $13,360 \pm 240$ RCYBP (ISGS-1264) and $13,340 \pm 180$ RCYBP (ISGS-1284) (Hajic, 1985a). Radiocarbon dates and the continuity of reddish-brown clay—from the near-surface in the valley-mouth sediment dam to basal lacustrine deposits—indicate that the period of Mississippi valley aggradation responsible for construction of the sediment dam was nearly completed by about $13,300$ RCYBP. They also mark the initiation of the Deer Plain phase of Lake Calhoun. Elevations of the sediment dam and documented wave-cut scarps preserved beneath Illinois valley-margin alluvial fans, along with soil-geomorphic relationships on the Deer Plain terrace, indicate that the entire lower valley and considerable reaches of most tributary streams were inundated.

Final accumulation of Deer Plain-related deposits, lake drainage in response to Mississippi River downcutting, and exposure of the lake plain pre-date $12,000$ RCYBP, but may post-date about $12,400$ RCYBP. Wood collected from silty clay and sand beneath a younger (Keach School) terrace remnant (Butzer, 1977) inset into the Deer Plain terrace dated $12,000 \pm 100$ RCYBP (Hajic, 1985a). Wood from Lake Calhoun silt in the upper part of the lower Illinois valley dated $12,360 \pm 240$ RCYBP (ISGS-1283) (Hajic, 1985a), and a date of $12,325 \pm 75$ RCYBP (ISGS-415) (Butzer, 1977) was obtained from lake-margin sediments of the Deer Plain phase (Hajic, unpublished data).

Flock (1983) names and describes near-surface sediments of the Savanna terrace, the highest extensive Mississippi valley terrace lacking a loess mantle and correlates the Deer Plain terrace as part of the Savanna terrace. Flock characterizes the upper 1 to 3 m of Savanna terrace sediment as being dominated by interbedded chloritic and kaolinitic red clay, which had a Lake Superior source, and montmorillonitic gray clay, whose source was Lake Agassiz and possibly other temporary lakes west of the Superior basin. Not fully recognizing the lithofacies associations and polygenetic origin of Deer Plain deposits, Flock (1983) erroneously applied several of Hajic's dates (ISGS-894, ISGS-875, and ISGS-900) from basal Deer Plain lacustrine deposits in the lower Illinois valley to the Savanna terrace in general. He concluded that deposition of basal Savanna terrace sediments began after $13,100$ RCYBP. When taken in proper context, however,
the dates indicate that most Mississippi valley aggradation related to the Savanna terrace occurred before about 13,300 RCYBP, although the age of the base of the Savanna terrace remains uncertain.

At the mouth of the Illinois valley, are remnants of a second, most likely pre-Holocene terrace lower than and adjacent to the Deer Plain terrace. Up to 2.5 m of bedded silt to loam overlies cross-bedded sand containing rip-up clasts of olive-gray and reddish-brown clay and ripple-drift cross-laminated sand. This terrace indicates another episode of Mississippi valley aggradation sometime after about 12,400 RCYBP, which has yet to be investigated in detail and related to Illinois valley deposits.

Wood collected from sandy outwash 7 m below a terrace surface at the mouth of the nearby Missouri River dated 12,148 + 700 RCYBP (Flint and Deevey, 1951). Flint and Deevey (1951) correlated the terrace with the Festus terrace of Robertson (1938). Goodfield (1965) suggested that the terrace could possibly be a Deer Plain terrace remnant. If the date is valid, the terrace probably is not Deer Plain, but rather a younger terrace possibly related to the remnants of the second terrace at the mouth of the Illinois valley.

A second pre-Holocene phase of Lake Calhoun, which was initiated by about 10,500 years ago in the lower Illinois valley, lasted until about 9800 years ago. The lake of this younger, Keach School phase was considerably lower than during the preceding Deer Plain phase.

The Keach School terrace (Butzer, 1977) provides morphologic and sedimentologic evidence for the lake phase (Hajic, 1983; Styles, 1984). Below the Keach School terrace surface, as much as 2.5 m of laterally continuous, thin beds of silty sand, silt, and sandy clay are underlain by cross-bedded and horizontal-bedded sand to pebbly sand well over 10 m thick. Butzer (1977) interpreted the sequence as outwash deposited by a braided river. However, there is no evidence of braided channels on even the largest remnants of the Keach School terrace, which is nearly level over its extent and post-dates deposition of outwash in the valley. The Keach School terrace probably represents a lake plain underlain by a thin unit of lacustrine deposits which in turn are underlain by older outwash deposits. The northernmost part of the terrace occurs along a chain of older terraces that diagonally cross the valley and may represent the lakeshore of the Keach School phase. Finally, slackwater silt deposits in tributary valleys grade to the Keach School terrace. Organic matter from a laminated silt deposit just above the elevation of the Keach School terrace at the mouth of Napoleon Hollow dated 9950 ± 260 RCYBP (ISGS-819) (Styles, 1984). Wood from a corresponding laminated silt deposit in Campbell Hollow across the Illinois valley from Napoleon Hollow dated 10,460 ± 220 RCYBP (ISGS-989) (Hajic, 1985b).

The Pleistocene-Holocene transition in the lower Illinois valley was marked by lake drainage and a period of incision when channels were downcut about 15 m in response to Mississippi River downcutting. Incision was rapid, and occurred by about 9800 years ago. Wood recovered from thinly bedded to laminated, fine-textured sediments filling an abandoned tributary creek meander belt incised into a Keach School terrace remnant dated 9750 ±
Termination of the Keach School phase with lake drainage, Illinois River downcutting in response to Mississippi River downcutting, and exposure of the lake plain as the Keach School terrace pre-dates this age but is younger than about 9,950 years.
THE PLEISTOCENE STRATIGRAPHY OF THE
BUFFALO RIVER VALLEY, WISCONSIN

R.D. Dunning
Department of Geography
University of Wisconsin, Madison

The geomorphology and stratigraphy of the Buffalo River valley, Wisconsin, provide a complex record of late Quaternary environmental changes. This paper summarizes the distribution, stratigraphic relations, and sedimentology of the terraces and alluvial deposits and their implications for understanding Pleistocene environments in the region.

The Buffalo River is a tributary to the Mississippi River. Because of its location on the northern edge of the Driftless Area in western Wisconsin, the valley experienced the direct effects of pre-Wisconsinan glaciations encroaching on parts of the valley (Baker and others, 1983), as well as the later more indirect effects of Wisconsinan glacial advances in the region. Several major episodes of erosion and deposition within the valley took place during the Pleistocene as evidenced by the geologic record. The Driftless Area valleys, which were outside the glacial margins, commonly preserve an excellent record of Pleistocene environmental change.

Most of the recent research on the Quaternary history of the Driftless Area has focused on the southern part of that region (Knox, 1972; Knox and Johnson, 1974; McDowell, 1983). The Buffalo River eroded its valley deeply into Cambrian sandstone bedrock (in contrast to the carbonate bedrock farther south) and the sandy sediments of the valley fill materials are distinct from the gravels in the valley floors of the southern Driftless Area. As a result, the Buffalo River responded differently to later environmental changes and preserved a unique stratigraphic record which offers important correlative information about the Upper Mississippi valley during this time period.

Except for loess or loess-derived silty alluvium, most of the alluvial deposits in the valley have sandy textures. Detailed analyses of these sands show that quartz commonly comprises 95 to 100 percent of the individual deposits. In parts of the valley there are, however, outwash sands which have a high proportion of erratic rock fragments or, at other sites, highly glauconitic sands. In many cases, both outwash sands and glauconitic sands underwent extensive reworking in subsequent depositional episodes.

Originally the Buffalo River was a tributary to the Chippewa River, but it was captured by a smaller river and diverted to the southwest and into the Mississippi River (Martin, 1932). The post-capture valley configuration provides a potential spatial and temporal framework for separating different events in the valley's history. I studied the valley features in a series of cross-valley transects which show distinct geomorphic differences between the upper valley (above the capture point) and the lower valley (below the capture point).
Detailed sedimentologic analyses helped identify individual units within the valley fill material, and the results show different stratigraphic sequences in the upper and lower valleys. The upper valley is relatively wide and contains many terraces ranging in age from late Pleistocene to late Holocene. The highest terraces contain a unit of reworked outwash sands over reworked glauconitic sands, while the lower terraces are made up of local quartz sands. The deep valley fill material also consists of nearly pure quartz sands over a lag deposit of fine gravel containing erratic pebbles. In contrast, the lower valley is narrower and so contains fewer terraces. Again the terraces span the time period from late Pleistocene to late Holocene. The high terraces in the lower valley have a sequence in which reworked outwash and glauconitic sands overlie a deposit of outwash sand—a sequence which is very much like the deposits in the abandoned valley to the west of the capture point. The low terraces through the lower valley contain reworked outwash sands.

There are no absolute dates older than mid-Holocene available to define the timing of the older events. Longitudinal profiles of the terrace surfaces indicate that the high terraces in the upper valley are the oldest and that the outwash deposits in the lower valley relate to a younger depositional episode. A study by Andrews (1965) relates this outwash to Wisconsinan meltwaters from the Chippewa River which flowed up the abandoned Buffalo River valley and down the modern valley to the Mississippi. The distribution of terrace deposits supports that theory as a possible mechanism. Except for a few deposits protected by bedrock ledges, the terraces in the valley must all be younger than the deepest valley incision, and well records indicate that the deep incision occurred after the stream capture. If the stream capture can be related to the pre-Wisconsinan glacial advance from the west, which dammed many valleys in the Driftless Area (Baker and others, 1983), then the deepest incision and subsequent valley fills occurred since that time.
DEVELOPMENT OF THE MISSISSIPPI RIVER FROM LATE ILLINOIAN THROUGH EARLY HOLOCENE AS RECORDED IN TERRACE REMNANTS ALONG THE LOWER IOWA AND CEDAR RIVERS, SOUTHEAST IOWA

S.P. Esling and G.R. Hallberg
Southern Illinois University and Iowa Geological Survey

In Illinoian and Wisconsinan time, glaciers advancing westward across Illinois diverted the ancestral Mississippi River into a series of temporary channels in western Illinois and eastern Iowa (Trowbridge and others, 1941; Anderson, 1968). Once established in its present valley, the complex Holocene development of the river largely destroyed the evidence of the early Mississippi River valley history. However, a temporary diversion channel through eastern Iowa, which includes portions of the lower Iowa and Cedar Rivers, contains the remnants of three terrace systems—the early phase high terrace (EPHT), the late phase high terrace (LPHT), and the low terrace (LT)—which record the development of the Mississippi River. The terraces differ in topographic position, relationship to upland geomorphic surfaces, and stratigraphy of the underlying deposits (Esling, 1984).

EPHT deposits were originally attributed to Lake Calvin, a proglacial lake which supposedly occupied the lower Iowa and Cedar River valleys in Illinoian time (Schoewe, 1921). However, the terrace deposits and sedimentary structures show a fining-upward fluvial sequence, grading upward from gravel to fine sand and silty sediment. Wisconsinan loess and eolian sand (6-9 m thick), which locally includes colluvium and alluvium derived from upland side valleys, overlies the fluvial deposits. A paleosol with a significant textural B horizon separates the fluvial deposits from the overlying predominantly eolian deposits; the paleosol is continuous upslope with the Sangamon paleosol on the uplands.

Radiocarbon dates on organic carbon from the base of the loess and the A horizon of the paleosol range from 18,500 to 23,750 RCYBP with a mode around 22,000 RCYBP (Ruhe and Prior, 1970; Esling, 1984). Radiocarbon dates on organic carbon from the base of the upland loess deposits fall in the same range, indicating that the EPHT received a full increment of loess. The source of the loess, the Wisconsinan Iowa River floodplain (Lutenegger, 1978), must have been entrenched below the EPHT alluvial surface.

Two characteristics of the EPHT suggest that the fluvial deposits are late Illinoian to early Sangamon in age: (1) The terrace deposits are inset within, and must post-date, deposits of the early Illinoian Glasford Formation; and (2) the well-developed paleosol (the Sangamon) is indicative of development under interglacial conditions. The base of the EPHT alluvial deposits occurs at an elevation higher than the present floodplain. The bulk of the valley fill must be younger than the EPHT fluvial deposits (Fig. 1).

A preliminary analysis of terrace gradients and stratigraphy suggests that a terrace described by Frye and Willman (1965) along the Mississippi River valley near Marcelline, Illinois, is correlative with the EPHT. The EPHT is also similar stratigraphically to the Badden Terrace described by
Figure 1. Schematic section of the terrace systems and deposits of the lower Iowa River valley. 1, Holocene alluvium; 2, low terrace (LT) system deposits; 3, late phase high terrace (LPHT) system deposits; 4, early phase high terrace (EPHT) system deposits.
Goodfield (1965) which is located along the Mississippi River valley near St. Louis.

Deposits of the LPHT were also attributed to Lake Calvin (Schoewe, 1921), but a fining-upward sequence within the terrace deposits suggests a fluvial origin. Less than 4 m of eolian loess and sand overlie the fluvial deposits. The lack of a significant paleosol or weathering zone separating the fluvial deposits from the eolian deposits suggests that deposition of the loess occurred soon after deposition of the fluvial deposits. The end of loess deposition in eastern Iowa established a minimum age for the LPHT fluvial deposits at about 14,000 to 13,000 RCYBP (Esling, 1984).

The LPHT deposits resulted from a period of aggradation which coincides with Wisconsinan loess deposition in Iowa. The deposits of the aggrading Iowa River were the source of the loess which mantles the uplands and EPHT alluvial surface. Along the same reach of the Iowa River the EPHT and LPHT occur at similar elevations, indicating that fluvial aggradation continued to a level above the EPHT alluvial surface (the surface beneath the loess) (Fig. 1). In some areas LPHT deposits bury the EPHT deposits, but in general loess already in place protected the EPHT alluvial surface. The stratigraphy of the LPHT is similar to that of the Chain-of-Rocks terrace and Metz Creek terrace along the Mississippi River valley near St. Louis described by Goodfield (1965).

The LT is actually a system of unpaired fluvial terraces with similar topographic position and age. The fluvial deposits are mantled by thin discontinuous loess and eolian sand. Radiocarbon dates on organic carbon from the terrace fluvial deposits range from about 11,500 to 12,500 RCYBP (Ruhe and Prior, 1970; Nott, 1981). The terrace deposits likely span late Wisconsinan to early Holocene time. The LT system resulted from a period of aggradation which followed the incision that stranded the LPHT. An analysis of the LT gradient suggests that it is correlative with broad terraces in the Mississippi River valley at the mouth of the Iowa River near the town of New Boston, Illinois. This terrace may also correlate with those located in the Mississippi valley at Prairie du Chien, Wisconsin; Harpers Ferry, Iowa; Savanna, Illinois; and Muscatine Island, Iowa. Inset within the LT is a complex set of Holocene alluvial fills.

The sequence of the terraces and the stratigraphic relations of the deposits show that (1) the oldest alluvium is perched highest in the landscape; (2) successively younger deposits are inset, and these surfaces and deposits step-down to the modern valleys; and (3) the deepest entrenchment in these valleys occurred in the Wisconsinan. This pattern is consistent with field evidence from elsewhere in Iowa and Illinois. The terraces and their deposits in valleys tributary to the Mississippi can be matched to the patchy record preserved in the Mississippi valley.
USE OF CLAY MINERALOGY AND RADIOCARBON DATING IN THE INTERPRETATION OF SEDIMENTARY UNITS, MOUND CITY, ILLINOIS

Philip C. Reed, John M. Masters, and Herbert D. Glass
Illinois State Geological Survey

Two test borings, one north and the other south of the junction of the Cache and Ohio Rivers, penetrated 18 and 29 m of valley fill sediments, respectively. Radiocarbon dates, clay mineral composition data, and nuclear logs were used to correlate lithologies in 38 borings in a 3.2-km alignment along the Ohio River. The borings were completed as part of a U.S. Army Corps of Engineers project to obtain information on the hydraulic and engineering properties of earth materials along the Ohio River levee near Mound City, Illinois. The test borings are located on the floodplain of the Ohio and Mississippi Rivers, near the northernmost part of the Mississippi Embayment, about 10 km southeast of the mouth of the Ancient Cache-Ohio River bedrock valley. The valley fill sediments contain major contributions from nearby upland and valley wall deposits, such as those northwest and north of Mound City, Illinois, that consist of Paleocene, Eocene, and Pliocene-Pleistocene clays, silts, sands, and gravels. These valley fill sediments could have been deposited by the Mississippi, the Ohio, or both rivers combined. The redistribution of valley fill sediments is related to two distinct depositional periods when stream base levels were as much as 24 m below present altitudes.

Clay mineralogy was used in conjunction with sample descriptions and age dates to delineate four stratigraphic divisions in the test borings. High montmorillonite values characterize the marine clays of the Porters Creek Formation (Paleocene), while high kaolinite values dominate the overlying fluvial-littoral sand and clay of the Wilcox Formation (Eocene). In the Quaternary valley fill succession, a lower sand and gravel and silty clay deposit exhibits high montmorillonite values, and an upper silty clay deposit contains mixtures of montmorillonite, kaolinite, and illite.

The radiocarbon dates were obtained from wood collected at depths of 14.3 and 22.3 m below land surface in the northernmost well. The lowermost sample Juniperus sp. (juniper) was dated 1740 ± 70 RCYBP. It was taken from a split spoon in sand resembling Wilcox Formation materials. This wood was believed to have been incorporated in Wilcox Formation material, possibly through slumping or landsliding that occurred along a nearby Holocene channel margin, where exposed Wilcox sands would tend to be especially unstable due to the underlying Porters Creek clay. A radiocarbon date of 4050 ± 70 RCYBP was obtained from a conifer fragment (juniper) collected from a washed rotary sample in Holocene sand and gravel at 14.3 m. These dates imply the possibility that (1) during the Holocene, deep channels were eroded into Eocene age sediments; (2) juniper trees were living near these channels about 1700 years ago in deposits subject to landsliding; and (3) as sand and gravel was deposited in these areas, older Holocene organic materials (greater than 1700 years old), eroded from nearby uplands, were redeposited with the valley fill sediments. The traditional interpretation of this succession of sediments, without the radiocarbon dates, would have been: undisturbed Paleocene clay and Eocene kaolinitic sand, overlain by Wisconsinan, well-sorted sand and gravel (Mackinaw Member of the Henry Formation), overlain by Holocene silty clays (Cahokia Alluvium).
Commercial navigation has used the Upper Mississippi River for nearly 175 years. During that time, the river has undergone many navigation projects in an effort to increase main channel depth. The first improvement project completed by the U.S. Army Corps of Engineers consisted of the removal of snags and sandbars in 1824. The Rivers and Harbors Acts of 1878 and 1890 resulted in the construction of thousands of wing dams (dikes), revetments, and closing dams which were all used to provide a 4'/2-foot channel depth. In 1907 Congress authorized the 6-Foot Channel Project which was accomplished by adding additional wing dams and shore protection in addition to channel dredging. These channelization projects were designed to confine low flows to a narrower channel, thus increasing depth. Congress authorized the 9-Foot Channel Project in 1930 which resulted in the construction of 29 locks and dams on the Upper Mississippi between St. Paul and St. Louis. Viewed in longitudinal profile, the locks and dams on the Upper Mississippi River form a series of steps or pools during normal or low-flow periods. During high-flow periods, the gates are wide open at each dam and the river is essentially free-flowing.

Even though the general morphology of the Upper Mississippi River was essentially determined by glacial events in the Pleistocene, perhaps the greatest influence on the present Mississippi's geomorphology, sedimentology, and ecology has been the effects of its tributaries together with channelization projects. The Upper Mississippi exhibits a somewhat braided channel pattern, often referred to as "island braided." The river forms a network of vegetated alluvial islands and channels. Some Mississippi tributaries transport large volumes of coarse sediment into the Mississippi resulting in local aggradation and dislocation of the Mississippi main channel opposite tributary mouths. Lake Pepin is an excellent example of tributary damming of the Mississippi caused by deposition at the mouth of the Chippewa River. The sediment provided by some tributaries is often coarse enough to cause the Mississippi to form numerous bars and islands downstream from the tributary mouths, thus precipitating the island-braided pattern. Those tributaries that discharge higher percentages of suspended fine-grained sediments do not have such a dramatic effect on channel position of the Mississippi (e.g., Wapsipipinicon).

Wing dams primarily caused the riverbed to degrade in response to sediment aggradation between wing dams. The navigation dams on the Mississippi have changed the river from the old free-flowing river into a series of shallow impoundments that occupy most of the river floodplain. The locks and dams submerged the wing dams and resulted in substantial increases in channel width above each lock and dam. In most cases, the riverbed has aggraded above, and degraded below, each lock and dam. All non-main channel water areas are aggrading at rates of about 2-4 cm/yr.

Sediments produced by individual tributaries vary both in composition and yield because of differences in land use, topography, vegetation,
soils, and climate within the Upper Mississippi River basin. Sediment production by tributaries and sediment concentration in the river increase in a downstream direction. Tributaries draining intensely farmed areas underlain by loess soils generally have the highest sediment yields (e.g., Upper Iowa River). In contrast, tributaries draining forest-covered glaciated regions with sandy soils, have the smallest sediment yields per basin unit area. Such tributaries may, however, have high bed-load discharge rates caused by erosion of coarse glacial outwash stored in river valleys. Such tributaries contribute most to the dredging problems on the Mississippi (e.g., Chippewa and Wisconsin Rivers).

The 9-Foot Channel Project created three distinct ecological zones within each impoundment. The tailwater areas just downstream from each lock and dam consist of deep sloughs and wooded islands that are basically unchanged from preimpoundment time. The middle sections of most pools contain large open areas created by the inundation of hay meadows and logged portions of the forested floodplain. The lower pool areas located immediately above the locks and dams consist of wide open-water areas that are subject to high sedimentation rates. Marsh vegetation is gradually moving downstream in response to reduced water depths caused by siltation. The once biologically productive backwater areas created by the 9-Foot Channel Project have degraded because of accelerated siltation and subsequent depth reduction. Maintenance dredging by the U.S. Army Corps of Engineers has resulted in additional habitat loss.
REFERENCES CITED


Church, P.E., 1984, The archeological potential of Pool No. 10, Upper Mississippi River: A geomorphological perspective: Vicksburg, U.S. Army Corps of Engineers Waterways Experiment Station.


Hajic, E.R., 1983, Shallow subsurface geology, geomorphology and limited cultural resource investigations of the Hillview Levee and Drainage


Olsen, B.M., and Mossler, J.H., 1982b, Geologic map of Minnesota, depth to bedrock: Minnesota Geological Survey State Map Series S-14, scale 1:1,000,000.


Robertson, P., 1938, Some problems of the middle Mississippi River region during Pleistocene time: St. Louis Academy of Science Transactions, v. 29, no. 6, p. 169-240.


Thwaites, F.T., and Twenhofel, W.H., 1921, Windrow Formation; an upland gravel formation of the driftless and adjacent areas of the upper


The position of the quarry (Fig. 1), about 25 m (80 ft) below the crest of the ridge, is typical of quarries located along the Mississippi River in southeastern Minnesota (Fig. 1). Ridgetops are mantled by unconsolidated deposits, which may be as much as 15 m (50 ft) thick. Quarries are developed along the shoulders of ridges where carbonate bedrock is exposed and where overburden is thinnest. As a result, the thickest sections of unconsolidated deposits are not observed at quarries.

The lower part of the Prairie du Chien Group, the Oneota Dolomite (Fig. 2) is exposed in the quarry. At the top of the south headwall, where this stop is located, remnants of weathered sandstone derived from the overlying Shakopee formation occur.

The Prairie du Chien Group forms a resistant cap overlying approximately 280 m (900 ft) of poorly cemented Late Cambrian sediments. The contact between the Oneota Dolomite and Jordan Sandstone may be seen at the bench on the north end of the quarry.

There are three types of unconsolidated deposits exposed at this stop. Loess, believed to be late Wisconsinan, caps the section of this stop. It overlies two distinct types of reddish-colored sediment. Sandstone clasts and loose sand derived from weathering of the Shakopee Formation is thought to be the only bedrock residuum present. The other reddish sediment consists of till. Textural analyses of samples collected at this till are as follows:

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Unit</th>
<th>Gravel</th>
<th>Sand</th>
<th>Silt</th>
<th>Clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC8386-1</td>
<td>Till</td>
<td>0.4</td>
<td>31</td>
<td>27</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Till</td>
<td>2</td>
<td>29</td>
<td>31</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Loess</td>
<td>1</td>
<td>20</td>
<td>51</td>
<td>29</td>
</tr>
</tbody>
</table>

The 1- to 2-mm sand grains of the residual till and the basal portion of the loess are mostly quartz, derived from Precambrian rock types. The remaining fraction consists of insoluble siliceous grains weathered from Paleozoic rocks. Pebbles of rhyolite, gabbro, and agate occur in the surface lag of the till, but were not encountered in the grain counts. The presence of coarse sand and pebbles at the base of the loess may indicate a certain amount of "welding."

The area covered by residual till in Minnesota is relatively small and restricted to the interfluves, although a thin lag of erratics occurs on the shoulders of interfluves. Near Wilson, about 3 km (2 mi) south of the Anderson-Quavery Quarry, the residual till overlies a thin layer of loess, presumably derived from a previous ice advance. Where till overlies the loess, it is siltier than elsewhere, implying some local incorporation of loess.

Virtually all carbonate bedrock in southeastern Minnesota shows evidence of solution weathering. Surface exposures, caves, and drilling data
Figure 1. Stop #1—Andersen-Quavery Quarry along Minnesota Highway 12.
Figure 2. Generalized bedrock stratigraphy and relative positions of field stops (circled numbers). West of Stop 8, about 120 m (400 ft) of younger carbonate rocks overlie the Galena plateau.
indicate that karst development persists throughout the Paleozoic section to depths exceeding 75 m (250 ft). Solution features are closely associated with the geomorphic history of this area. New solution features may result from valley entrenchment, at the same time pre-existing solution features may influence the position and rate of downcutting. Clearly attention must be focused on relating karst development to regional hydrogeology as it pertains to the development of the Mississippi River valley.

Sinkholes and cutters exposed in the quarry walls are examples of the solution weathering within the Oneota Dolomite. Reddish-brown sediments fill these solution features and document the interconnection of surface water and ground water. No detailed studies of these red sediments have been made in southeastern Minnesota. Previously such deposits were assumed to be terra rossa. However, the materials exposed at this stop show that only a fraction of the reddish sediment is in situ carbonate bedrock residuum.

Discussion. The unconsolidated deposits that are observed at this stop were formed by different processes and demonstrate that a complex history of erosion and sedimentation has occurred on the surface of the Prairie du Chien plateau.

1. What relationship, if any, exists between the in situ weathering of local bedrock, the solution weathering of the Prairie du Chien dolostones and younger carbonate bedrock, and the sediments which fill the sinkholes?

2. Why is the residual till found only on the interfluves and not in the adjacent valleys?

3. What are the stratigraphic relationships between the bedrock residuum, the residual till and the loess?

At subsequent field trip stops, geomorphic features and sediments associated with erosion of Paleozoic bedrock and with the Quaternary history of southeastern Minnesota will be presented. The positions of these stops relative to the bedrock stratigraphy are shown in Figure 2.
STOP #2 WINONA COUNTY LANDFILL

The landfill property provides an excellent view of the valley and ridge topography adjacent to the Mississippi River valley in southeastern Minnesota. Test drilling and excavations at the landfill give insight into relationships between local geologic conditions and geomorphology.

Steep valley walls stand in marked contrast to the relatively flat-topped ridges which extend from the broad upland plateau. An intricate dendritic stream drainage has cut into marine sedimentary rocks of Paleozoic age. Lower Ordovician dolostones, which comprise most of the Prairie du Chien Group, are much more resistant to erosion than the underlying sequence of Upper Cambrian sandstones, siltstones, and shales. Thus, the Prairie du Chien caps the ridges and forms a broad plateau throughout much of southeastern Minnesota.

The Prairie du Chien Group is the stratigraphically lowest resistant unit that the Mississippi River had to breach before the entrenchment of its present canyon could occur. Many of the field trip stops exhibit geologic relationships or geomorphic features associated with the Prairie du Chien plateau and raise questions about the history of the Upper Mississippi River valley.

Local bedrock structures. Bedrock jointing appears to have strongly influenced the orientation of local stream drainage. Compare the jointing directions at outcrops along the landfill ridge with topographic lineations (Fig. 1). It is logical to assume that stream erosion would be most aggressive along trends of highly fractured bedrock. In estimating the effects of bedrock jointing on the development of topographic lineation, outcrop orientations should be considered. If an outcrop locally parallels the trends of master joint sets, then only the face of an exposure remains to portray this relationship, and joints actually measured at any exposure will most likely be only secondary or less dominant directions of fracture.

Topographic lineaments for the landfill ridge and adjacent valleys were determined from 1:24,000-scale topographic maps. The orientations of wide valley segments are shown on Figure 1 as open arcs while those of ravines and small valleys are shown as filled arcs. Clearly, the directions of measured joints and the trends of ravines and small valleys are related. Outcrop orientations are more closely parallel to large valleys than are the directions of measured joints. Master joint sets probably influenced the orientation of master stream drainages and still control the directions in which exposed bedrock will spall due to weathering.

The relationship between the orientations of large tributary valleys and the strike of local bedrock structures is not well understood. The landfill ridge is underlain by a local structural high which plunges into a small basin that extends at least to the Mississippi River valley (Fig. 2). Sugar Loaf Hill, which can be observed from the landfill, provides a reference for appreciating the small-scale nature of local bedrock flexure. The Witoka Dome is the best known structural feature in Winona County, but it too exhibits only a small displacement of about 30 m (100 ft).
Figure 1. Stop #2—topographic lineation and bedrock jointing at the Winona County landfill.
Figure 2. Structural contour mapping of the top of the Jordan Sandstone (i.e., base of the Prairie du Chien Group) near the Winona County landfill. Contour interval = 20 feet.
There appears to be no direct relationship between geomorphology and bedrock flexure. Both valleys and ridges occur over structural highs and lows. As the top of the Prairie du Chien Group was exposed to weathering, closely spaced joints related to local flexure probably influenced stream positions. Also, prior to development of the present gently rolling plateau, the Prairie du Chien surface may have exhibited more relief due mostly to local flexure. Structurally low areas were probably topographically low and received runoff from structurally high areas such as Witoka Dome. However, jointing was still the major factor controlling the rate and orientation of stream dissection.

Surficial materials. Soil borings data and excavations at the landfill show a great diversity in the lithology and thickness of the unconsolidated deposits covering the Prairie du Chien. Small isolated knobs of bedrock occur within about a meter (a few feet) of the land surface juxtaposed against unconsolidated materials tens of feet in thickness. Glacial erratics have not been observed associated with these deposits, which appear to be derived from local bedrock types. Soil borings have penetrated as much as 12 m (40 ft) of interlayered yellow-brown to red-brown sandy, silty clay, clayey sand, fat clay, and reworked sandstone (Fig. 3). Incorporated with these sediments are angular to rounded fragments of carbonate bedrock, ranging in size from cobbles to boulders over 2 m (6 ft) in diameter. The textures and lithologies of the unconsolidated deposits at the landfill suggest a fluvial or colluvial origin rather than deposition by ice or wind.

Discussion. The Prairie du Chien and the underlying sequence of less resistant Cambrian strata appear to have affected the geomorphic development of the present tributary drainages by controlling the rates and directions of stream erosion, and probably influenced at least the initial development of the Mississippi River valley as well. If the Prairie du Chien plateau provides a surface of reference for the downcutting of the Mississippi River and its tributaries, the following questions arise:

1. Within the entire dendritic drainage system, are all equal-order valleys isochronous?

2. In which direction or directions would the widening of the Mississippi River valley have occurred?

3. Has the widening of the Mississippi River valley occurred at a faster rate than the widening and deepening of the major tributary valleys?

The unconsolidated deposits which mantle the Prairie du Chien at the landfill do not appear to have the same origins as the bedrock residuum, "residual till," or loess at the Anderson-Quavery Quarry (Stop 1). The incoherent assortment of lithologies at the landfill suggests a colluvial origin or colluvium reworked by the stream action.

4. What are the stratigraphic relationships between the unconsolidated deposits at the landfill, as compared to those at the quarry?

5. Why are loess and the "residual till" not found at the landfill if this area was once a local depositional lowland?
<table>
<thead>
<tr>
<th>Location</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>B36</td>
<td>FILL? Mostly lean clay</td>
</tr>
<tr>
<td></td>
<td>LEAN CLAY brown</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY brown</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY brown mottled</td>
</tr>
<tr>
<td></td>
<td>CLAYEY SAND brown to reddish-brown mottled</td>
</tr>
<tr>
<td></td>
<td>SILTY SAND fine grained, brown to reddish-brown mottled</td>
</tr>
<tr>
<td>B31</td>
<td>FILL Mostly lean clay</td>
</tr>
<tr>
<td></td>
<td>LEAN CLAY brown</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY brown mottled</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY brown to reddish-brown</td>
</tr>
<tr>
<td></td>
<td>CLAYEY SAND fine to medium grained, reddish-brown</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY reddish-brown</td>
</tr>
<tr>
<td>B15</td>
<td>SILTY CLAY reddish-brown</td>
</tr>
<tr>
<td></td>
<td>WEATHERED SANDSTONE</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY reddish-brown</td>
</tr>
<tr>
<td></td>
<td>CLAYEY SAND fine to medium grained</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY reddish-brown</td>
</tr>
<tr>
<td></td>
<td>DOLOMITE BOULDER</td>
</tr>
<tr>
<td></td>
<td>FAT CLAY reddish-brown</td>
</tr>
<tr>
<td></td>
<td>ONEOTA DOLOMITE medium to thick bedded slightly vuggy</td>
</tr>
</tbody>
</table>

**Figure 3.** Variability of lithologies in the unconsolidated deposits at the Winona County landfill.
6. Could the area around the landfill once have been a lowland where colluvium accumulated? If so, where was the source area for this sediment? Would East and West Burns valley have been entrenched below the base of the Prairie du Chien at this time?

7. What might Stops 1 and 2 tell us about the history of this ridge and the history of the Mississippi River valley?
The Oneota Dolomite near its contact with the Jordan Sandstone was quarried here along a small tributary valley of the Whitewater River (Fig. 1). At this stop, the Oneota is more heavily jointed and shows more extensive solution weathering than at Stop 1. Reddish-brown till mantles the Oneota Dolomite at the road cuts along Winona County 26 uphill from the quarry. The Whitewater River drainage has heavily dissected the Prairie du Chien plateau north and west of this stop. To the east, a well-developed, but no longer major, bedrock drainage system terminates in the Rollingstone valley, where there are no master streams, and only intermittent streams exist.

On the north face of the quarry is a small cave filled with sediment, consisting of pale-brown (7.5-10YR 6/3) silt loam and strong-brown (7.5YR 5/6, 4/6) clay and clayey sand. Some of the clay beds are very dark gray to black (10YR 3/1, 2/1) and very pure (97% clay in one analysis). All of the sediment is noncalcareous.

Grain counts of the 1- to 2-mm sand fraction of one sample identified Precambrian, Paleozoic, and what were believed to be Cretaceous grains. Most of the Precambrian fraction consisted of quartz with minor amounts of feldspar and metamorphic grain types. Grains thought to be derived from Cretaceous Ostrander-type deposits included polished quartz, chert, and goethite. The Paleozoic grains were mostly siliceous, and probably derived from weathering of the Prairie du Chien Group and the St. Peter Sandstone. Grain counts were not made of the gravel or <1-mm size fractions, but the same rock types were observed. The composition of the fill suggests that the source of the material included till, bedrock residuum, and possibly loess.

Judging from the pure clay and the silt and clay content of the sand, the cave must have provided a low-energy environment of deposition. Sediment influx was probably intermittent, occurring when material could be washed in along solution-enlarged joints. The bedding orientation of the fill ranges from horizontal to vertical and indicates that the cave was probably part of a developing network of solution cavities and subsurface drainage. Solution cavities tightly packed with sediment are very common in the area of the Prairie du Chien plateau. Waxy red clay, which fills joints in the underlying Jordan Sandstone, may come from the solution cavities rather than weathering of local carbonate rock.

The road cuts along County Road 26, uphill from the quarry, are capped by a reddish-brown sediment containing pebbles and cobbles of Precambrian igneous and metamorphic rock types. This is believed to be the same "residual" till as that observed at Stop 1. The road cuts are slightly higher in elevation than the cave, and it is possible that some of the cave sediment was derived from this "residual" till.

Discussion. The "residual" till overlying the Oneota Dolomite in this area indicates that a topographic low was established well into the Prairie du Chien Group prior to till deposition. The Oneota Dolomite is more chemically and mechanically weathered in this part of Winona County than where
Figure 1. Stop #3—quarry and sediment-filled cave northwest of Altura along Winona County Road 26.
it is exposed to the south and east. A possible explanation is that the Oneota was exposed to subaerial erosion in northern Winona County for a longer period than in the south. If so, the development of stream drainage in this area may be older and may have been more radically affected by glaciation.

1. Was the topographic low the result of the solution weathering and collapse or the result of stream dissection of the Prairie du Chien plateau?

2. Could the development of the Whitewater River system have captured much of the drainage originally flowing over the Prairie du Chien plateau to the Rollingstone valley, thereby leaving that bedrock valley system with no master stream?

3. "Residual" till has been observed at both Stops 1 and 3. What does this indicate about the age of the Prairie du Chien plateau and the age of the valley systems at these stops?

Some of the cave fill exposed at the Steiger Quarry may have predated the glaciation that deposited the "residual" till. Whether this cave formed prior to the development of the Whitewater drainage system or subsequent to downcutting through the Prairie du Chien cannot be readily determined. Caves like this occur in the Oneota Dolomite throughout the area and many are stratigraphically higher.

4. Would the cave at the Steiger Quarry have been below the water table when it was being filled?

5. What, if any, relationships exist between the formation of caves in the Oneota Dolomite and the downcutting of bedrock valleys?
This sandpit is located in a lower terrace system which slopes from about 240 m (800 ft) at this stop (Fig. 1) to about 224 m (740 ft) above m.s.l., where the Whitewater River joins the Mississippi River approximately 19 km (12 mi) downstream. The elevation and gradient of this system is typical of the late Wisconsinan terraces studied in Winona County. The terraces are fairly wide and continuous in the lower reaches of the Whitewater River, but rather small and sporadic upstream where they are not readily visible on topographic maps or air photos and require field study to be identified.

This terrace is composed of clean sand, thin gravelly beds, and thin beds of fine silty sand. Bedding is generally flat, with only minor cross-bedding. The sandy terrace is covered by about 3 m (10 ft) of silt. The upper part is unbedded and appears to be loess. The bedded silt contains some fine sand. The contact between the sand terrace and the silt cap is sharp, but highly contorted.

The pebble assemblage includes igneous and metamorphic rock types of glacial origin, as well as carbonate and chert, believed to be derived from local Paleozoic bedrock. The 1- to 2-mm sand fraction is predominantly quartz and feldspar, also likely to have been of glacial origin. Only about 10 percent of the grains appear to come from Paleozoic rocks. A very small fraction appears to be derived from Cretaceous rock types, predominantly the Ostrander gravels.

Discussion. Outwash deposits occur near valley headwaters on the uplands to the south and west, which are mantled by a till best exposed near St. Charles (Stop 5).

1. Did meltwater from the ice advance which deposited the upland till drain through the Whitewater River valley?

2. Was the terrace at this stop formed as an outwash terrace, or is the material reworked outwash not directly associated with deposition by a meltwater event?

Late-Wisconsinan terraces in Winona County are typically composed of silt over sand, with an irregular contact. Sand composition may be dominantly glacial material, as at this site, or dominantly weathered, local bedrock. The sequence at this stop may represent an overbank silt which covers channel sand that was deposited during one episode of meltwater drainage. On the other hand, the sand and some of the silt may have been deposited in braided streams prior to loess deposition.

3. Did these streams aggrade significantly prior to loess deposition in the late Wisconsinan, or was the loess the main reason for aggradation?

4. Are terraces the main or only source of information on pre-Wisconsinan streams?
Figure 1. Stop #4--sand pit in Whitewater valley near Elba along Minnesota Highway 74.
STOP #5 "ST. CHARLES TILL" EXPOSURE SOUTH OF UTICA

This stop (Fig. 1) is at the eastern edge of the St. Peter escarpment (Stop 1, Fig. 2) where an outlier of St. Peter Sandstone is capped by till informally named the St. Charles till. The Prairie du Chien Group forms a gently rolling plateau that extends eastward to the Mississippi bluffs. Depth to bedrock over on the plateau is generally less than 10 m (30 ft), and sinkholes are common. No loess is present at this stop; presumably we are within the late Wisconsinan "Iowan" erosion surface. The edge of the Des Moines lobe ice advance (the Bemis moraine) lies about 60 km (36 mi) to the west, and no outwash from late Wisconsinan ice has been found in this area.

From this stop, the Prairie du Chien and stratigraphically higher plateaus (Fig. 2) are all visible. The flat-topped hill west of County Road 33 is an escarpment of St. Peter Sandstone capped by the Platteville limestone. The Platteville is about 7 m (20 ft) thick and tends to form isolated mesas along the edge of the Galena plateau. A remnant of the much thicker Galena plateau is visible about 3.8 km (2 mi) to the south.

The St. Charles till at this stop is a calcareous, pebbly loam or clay loam, approximately 2 m (8 ft) thick. Only the upper meter (2 to 3 ft) of it is leached. At the top, the till is a uniform yellowish brown (10YR 5/4), grading downward through a light gray (2.5Y 6/2) to the base, which is strongly iron stained (10YR 4/6, 4/8). Secondary carbonate deposits are common in the lower part of the exposures.

Grain counts of two samples showed Platteville limestone, probably locally derived, occurring in the till, along with iron oxide, quartz, basalt, and greenstone. Granite was not common in the pebble fraction, but made up about half of the 1- to 2-mm sand. The remainder of the sand fraction is mostly Paleozoic carbonate grains and metamorphic rock fragments. One sample contained about 10 percent limonite and limonite-cemented till fragments. Both samples had minor amounts of polished quartz and chert, believed to be from the Ostrander Members of the Cretaceous Windrow Formation.

The thin leached zone, the moderate degree of oxidation, and the relative soundness of the pebbles might imply that the St. Charles is a young till, although it is well beyond the known boundary of the late Wisconsinan Des Moines lobe advance. It was mapped as "Kansan" by Leverett (1932). A probable explanation for its relatively fresh appearance is that much of the leached and oxidized till was removed by the same process which removed the loess. Where thick loess overlies the St. Charles till, the till is commonly leached and oxidized. Cuttings samples from a well about 12 km (7 mi) southwest of this stop show 8 m (25 ft) of St. Charles till overlain by 5 m (15 ft) of loess. The 3 m (10 ft) of the till are highly leached and oxidized, and the lower 5 m (15 ft) are gray and unleached. Both zones have the same pebble lithologies.

Discussion. The St. Peter escarpment has been eroding to the west, perhaps since the end of Cretaceous time. It presumably did not exist when the Ostrander gravel was deposited, because the polished pebbles of Precambrian
Figure 1. Stop #5--till over St. Peter Sandstone along Winona County Road 33.
rock types from Wisconsin were transported by streams flowing across a westward-sloping peneplain—transverse to the trend of the St. Peter escarpment. Also the escarpment faces east and north.

Soils mapping and subsurface data indicate that St. Charles till overlies the Galena plateau, the St. Peter escarpment, and the Prairie du Chien at least 5 km (3 mi) east of this stop. Thus the St. Peter escarpment was eroded to near its present position prior to the deposition of the St. Charles till.

1. If the St. Peter escarpment had eroded this far from the Mississippi channel prior to the till deposition, would this mean that the Mississippi valley also had breached the Prairie du Chien prior to deposition of the St. Charles till?

2. To what degree was stream drainage developed on the Prairie du Chien plateau prior to deposition of the St. Charles till?

One unresolved question in interpreting the history of this area concerns the St. Charles and the "residual" till. The 1- to 2-mm sand fraction of the "residual" till is basically the same as the leached samples of St. Charles till. However, the two units have not been observed in superposition in Winona County. The St. Charles till is typically loam to clay loam; the "residual" till varies from clay to sandy loam. Samples from the "residual" till contained more clay than silt; the reverse was true for the St. Charles till.

3. Are the St. Charles till and the "residual" till two distinct till sheets or facies of the same till sheet?

Figure 2. Schematic diagram of the lithostratigraphic and geomorphic relationships of the plateau-forming units in southeastern Minnesota.
STOP #6 CEMENTED GRAVEL NEAR CLYDE

This site is also on the edge of the St. Peter escarpment, and is similar to the setting of Stop 5. A low ridge of St. Peter Sandstone is flanked by two intermittent streams which are part of a branching drainage that has isolated several small "mesas" capped by Platteville limestone (Fig. 1). This drainage cuts through the Quaternary section to the southeast and flows across the Prairie du Chien plateau into the meander valleys of the upper Rush Creek drainage system (Stop 7).

Exposed on the north side of the highway are about 1 to 1.5 m (4 ft) of till overlying about 0.5 m (2 ft) of sand and gravel, which in turn rests on St. Peter Sandstone. The till is a calcareous pebbly clay loam. The upper part is yellowish brown (10YR 5/4), grading downward to grayish brown (10YR 4/6-2.5Y 5/3). No loess or leached till were observed, although they may exist in the 2 m (6 ft) of unconsolidated sediments that overlie the exposure. This site is believed to be outside of the "Iowan" erosion surface.

The gravel immediately below the till is largely cemented with calcite. Where it is not cemented, it is heavily iron stained, and small areas are manganese stained. The most common rock type in the gravel is subrounded dolomite, believed to be locally derived from Paleozoic bedrock. Erratic pebbles include granite, basalt, schist, rhyolite, and Ostrander pebbles. A cobble of till was observed partly imbedded in the St. Peter Sandstone.

Generally the St. Peter Sandstone is almost pure quartz and is friable, but in places it is cemented by calcite. The cement in the St. Peter and in the gravel may have been deposited contemporaneously. A preliminary determination of the age of the calcite cement was made, using the uranium-series disequilibrium dating method. Three ages were obtained--148,000 ± 4000, 78,000 ± 2000, and 169,000 ± 7000. The scatter may indicate more than one episode of calcite deposition, or may be related to post-depositional migration of uranium. If the former is true, these ages fit well with the range of stalagmite dates collected from southeastern Minnesota. Additional dating of calcite cements is planned in order to establish a chronometric record surface calcite deposition.

Discussion. The original thickness and amount of erosion of the St. Charles till are unknown. In Winona County the thickest section of 8 m (25 ft) was seen in a well about 5 km (3 mi) southwest of this stop in a similar geomorphic setting.

1. Was this originally a thin till draped over a pre-existing landscape, or did the observed drainage develop on and erode a thick till sheet?

The cemented gravel may have been a proglacial outwash. From the present topography the obvious direction of meltwater flow was southeast toward the Rush Creek drainage system.

2. Would this have been the direction of flow during the St. Charles ice advance?
Figure 1. Stop #6--cemented gravel under till along Winona County Road 6 near Clyde.
Few studies try to relate the geochemical environment responsible for secondary calcite and mineral stains to the erosional and depositional history of an area. It is very possible that such studies may provide significant data on the geomorphic history of an area.

3. Do the calcite cement and the mineral stains on the loose gravel reflect separate events, or contemporaneous deposition?

4. What geochemical conditions are responsible for both types of deposits?

5. Do the secondary deposits represent climatic changes, ground-water movement, and/or changes in the surrounding topography?
Two remnants or "islands" of the upland plateau are visible at this stop (Fig. 1). They probably are not capped by the Prairie du Chien Group (Lower Ordovician), but are cored with Cambrian bedrock. The Jordan Sandstone, which lies directly under the Prairie du Chien, is exposed on the northeastern side of the larger "island."

Several very small ravines cut the meander scars along the east wall of Rush Creek valley, just north of the two islands, and the cores which separate them. The smaller of the "islands" may have resulted from the splitting and isolation of a former core; the larger "island" may have formed by isolation of a meander spur. The smaller "island" is similar in shape and orientation to the meander core which lies to the north. Further stream dissection of this core may result in another small elliptically shaped "island." Several meander spurs attached to the upland plateau by narrow ridges occur along the valley of Rush Creek until its confluence with the Root River at the city of Rushford (Fig. 2). Further erosion of these ridges would result in "islands" of bedrock separated from the valley walls similar to the larger "island" observed at this stop.

Two distinct morphologies may be observed in the shapes of bedrock valley segments (Fig. 2). The first will be termed "straight," for ease of reference, and consists of relatively linear main valley segments having tributary valleys at acute or even right angles. The headwaters of many "straight" valleys have a tapered or somewhat rounded appearance. This is the most common shape for valleys entrenched into the Prairie du Chien Group in southeastern Minnesota.

The second morphology consists of entrenched meanders generally located in the headwaters or the upper portions of a valley. Meandering channels always terminate in "straight" valleys downstream. For discussion purposes, meandering valley segments will be termed "pigtail" valleys rather than the term "entrenched meander," which in the classical sense would imply uplift in addition to downcutting. There is no evidence to indicate that significant uplift occurred in southeastern Minnesota during Quaternary time. "Pigtail" valleys are not believed to have resulted from uplift.

Discussion. Meltwater from the glacier which deposited the St. Charles till (Stop 5) flowed down Rush Creek and Pine Creek. It is suggested that the "pigtail" valleys in this drainage system were meltwater channels which directed short-lived, but high-volume discharge over the Prairie du Chien plateau near its terminus. Meltwater streams may have been less competent braided streams flowing over the plateau toward the ancestral Rush Creek drainage. However, as meltwater was concentrated in the ancestral Rush Creek, the stream gradient increased dramatically as did the ability of the meltwater to remove any unconsolidated deposits mantling the Prairie du Chien surface. Then downcutting of the Prairie du Chien would have begun, but would have been controlled by jointing. This meltwater channel may have had a saw-tooth shape, but high-velocity abrasion rounded the bends, which had formed by local shifting of the channel, to accommodate a more dominant direction of jointing. Judging by the size of the meanders, the entire valley bottom must have been a channel, and the discharge at least
Figure 1. Stop #7—geomorphic features in upper Rush Creek valley.
Figure 2. Surface topography of the Rush Creek valley system. Scale = 1:62,500 (1 inch = 1 mile). Box shows area of Figure 1.
an order of magnitude greater than the present streams. Once established, a "pigtail" valley would become entrenched in the Prairie du Chien and would widen and straighten by eroding the necks of meander cores and spurs, particularly at the mouths of other valleys. The widening and straightening of a "pigtail" valley would have been accelerated once the Prairie du Chien was breached and undercutting began in the less resistant Cambrian section. Repeated meltwater discharges would create pigtail segments upstream but would also tend to straighten pigtail segments downstream, especially where the Prairie du Chien cap was removed. Once "islands" lost their Prairie du Chien cap, they would be very susceptible to erosion and would tend to be removed. As a result, a small "pigtail" valley could become a larger "straight" valley with few bedrock "islands".

The following questions arise:

1. Do "straight" valleys with no "pigtail" component represent interglacial or even preglacial stream erosion?

2. What would the confluence of a "pigtail" valley and a "straight" valley imply to glacial history?

3. How many episodes of meltwater erosion have occurred in Rush Creek valley?

4. Where might the headwaters for Rush Creek valley have been prior to meltwater erosion?

5. Why doesn't the Mississippi River valley have a "pigtail" morphology?

6. At what stage in the history of a "pigtail" valley are bedrock islands formed? The Mississippi River valley contains bedrock islands. What mechanisms other than meander core isolation would have produced these bedrock islands? What would the presence of bedrock islands in the Mississippi River valley signify?

7. Would it be possible to map the extent of an ice sheet on the basis of the distribution of "pigtail" valleys? If so, where would the terminus for the ice have been in the vicinity of Rush Creek and Pine Creek valleys?
We will be visiting the commercial tour of Mystery Cave No. 1 (Fig. 1) and will see late Wisconsinan gravels and associated flowstone deposits; the silts discussed below are not on the commercial tour.

Mystery Cave has developed over 18 km (11 mi) of passages within Upper Ordovician to Middle Devonian limestones and dolostones. The cave is located in a bend along the South Branch of the Root River, about 37 km (22 mi) east of its headwaters. The edge of the late Wisconsinan Des Moines lobe advance lies about 50 km (30 mi) west of the cave. Both the cave and the headwaters of the Root River are within pre-late Wisconsinan glacial material. Mystery Cave is about 180 m (600 ft) above the level of the Mississippi River, and about 45 m (15 ft) below the upland surface. At the present time, the lower cave is a meander cutoff for part of the Root River drainage. The water that enters at the Mystery 1 entrance (elevation 375 m (1230 ft) above m.s.l.) and at other points along the meander loop, resurges at Seven Springs (Fig. 2; elevation 350 m (1150 ft) above m.s.l.), about 2.1 km (1.3 mi) from the entrance to Mystery 1.

Mystery is a maze cave developed beneath about 2 km² (0.8 mi²) of surface area. Passages contain silt- to cobble-size sediments, which are mostly of fluvial origin, breakdown blocks of limestone, and various types and quantities of flowstone. Lower level streams have removed sediments by sapping, reopening many upper level passages once filled with fine silt-size sediment. Cave passages exhibit evidence of phreatic, epiphreatic (water table), and vadose development. Bedrock jointing has strongly controlled the development and the direction of the cave passages (Fig. 1). The dominant joint directions in this area strike east, northeast and northwest.

The study of cave sediments and associated speleothem development has helped to identify sources and stream-flow relationships and tie them into events that occurred at the surface. The oldest U-series ages as yet obtained for speleothem growth in Mystery Cave are about 161,000 years and indicate that major cave formation and sedimentation occurred prior to 160,000 years ago. Subsequent cave development and speleothem growth represent the emergence of lower drainage routes and removal of sediments from upper routes. Speleothems have not yet been found within or beneath the silts which fill the passages, although it is likely that they once existed. The composition of the unconsolidated sediments has been described by Milske (1982) and Milske and others (1983). The sediments consist of silt, sands, and gravel; very little clay is present in the sediments studied. The stratigraphic sections from the three areas studied are shown in Figure 3. The gravels in the sediment sections appear to have been derived from pre-Wisconsinan till, patches of which remain on the uplands to the west. However, this conclusion is tentative until more detailed studies of the surface materials in the area are made.

In its present physical state, Mystery Cave is a record of processes which can be related spatially and temporally to events occurring on or near the surface. In terms of the history of the Upper Mississippi valley, Mystery is a model of how karst, sediments, and geochronology combine to
Figure 1. Stop #8—Mystery Cave in relation to surface topography (from Milske and others, 1983). Cross section A-A' is shown in Figure 2.
provide a record of processes and events that may no longer be visible or recoverable on the surface.

The general sequence of events leading to the present Mystery Cave system is thought to be as follows: Early (but unspecified) development of a network maze pattern by diffuse ground-water infiltration prior to incision of the surface valley. The upper level is an epiphreatic or water-table cave, underlain by a network of deeper phreatic loops. As the Root River incised the valley, passage development became controlled primarily by direct input from the Root River, resulting in a floodwater maze cave. The basal silt at Enigma Pit and Fifth Avenue West (Fig. 3) once filled both levels of the cave. It was deposited when the cave was at or below the water table as a result of Root River backflooding, which created a temporary drop in flow velocity of sediment-bearing ground water, depositing silt, sand, and small amounts of clay. We have no way of knowing how long it took for the fill to accumulate or the reason(s) for the backflooding. The source of the silt is thought to be fine-grained carbonate and insoluble residue derived from shale beds in the Dubuque Formation.

Phreatic development ceased when headward incision of the surface valley allowed the cave to drain. On the basis of speleothem dates from the upper level, this appears to have begun by about 160,000 years ago in response to lowering of the regional base level. It may be significant that this occurred near the end of the Illinoian glacial cycle. As headward incision proceeded, more and more water from the river was channeled through the cave. The stream gradually lost competency to incise the valley, which now is partially or completely dry under low flow. Upstream from the sinkpoint at the cave, the river is perched 20 m (65 ft) above the stream level in the cave. It is evident from the Root River profile (Plate 1) that the stream channel near the cave is still a nick point at the top of the Galena.

![DISAPPEARING RIVER PROFILE MYSTERY RIDGE](image)

Figure 2. Cross section through Mystery ridge (from Milske and others, 1983). See Figure 1 for location.
Figure 3. Stratigraphic columns and dates from Mystery Cave (from Milske and others, 1983).
Between 160,000 years ago and the present, the cave system has seen the removal of the fine sediments, the growth of speleothems, the solution enlargement of lower levels, and the development of younger passages upstream from the original, upper level phreatic passages. Within this period, there were at least two episodes (approximately 145,000 and 13,000 years ago) of vadose stream deposition recorded in the Door-to-Door, Fifth Avenue West and Enigma Pit gravels (Fig. 3). These deposits lie between 15 and 26 m (45 to 78 ft) above the present stream level with paleoflow directions essentially parallel to the present system, and appear to represent short-lived episodes of channel aggradation during an otherwise fluviokarstic erosional cycle. The deposits were derived entirely from outside the cave, presumably from pre-Wisconsinan glacial drift and local deposits of Windrow gravel and iron ore. The episodes of gravel deposition correspond to the late stages of the Illinoian and Wisconsinan Glaciations, and were soon followed by periods of postglacial speleothem growth, between 160,000 and 100,000 years ago, and from 13,000 years to present.

Discussion. It is unlikely that backflooding from the Mississippi River would have reached the cave elevation. It seems more likely that local events, such as outwash or till, downstream in the Root River valley, were responsible for flooding in the cave.

1. Is Mystery Cave an example of Cretaceous or Tertiary development, or is it a younger cave formed as the result of subsurface and surface drainage during the Pleistocene?

2. A significant feature of the known history of Mystery is the timing of the draining of the cave and deposition of speleothems. Do these events accurately reflect the downcutting and headward erosion of the bedrock valley? Was the valley in place prior to the draining and, hence, do the silts and ages relate to glacial events? May similar cave systems have occurred along other meander loops?

3. The source of the sediments is apparently reworked glacial material originally deposited outside of the cave. Can we expect to find directly deposited glacial material within caves? Dating sediment deposition with speleothems is useful, but the dates are not easily correlated with events that occurred on the surface. How can we best tie the sediments found in caves into surface source and processes?
STOP #9 ALLUVIAL TERRACE NEAR RUSHFORD

Stop #9 is a sand pit on a terrace occupying a large meander scar in the Root River valley west of Rushford. It is evident from the topographic map that the terrace at Rushford exhibits a variety of elevations (Fig. 1). The sand pit is situated along a lower level scarp just above the modern floodplain of the Root River.

Beginning about 1.7 km (1 mi) upstream from the sand pit, the Root River valley abruptly narrows and is generally tightly meandered to its headwaters. In fact, the upper part of the Root River drainage system is the most tightly meandered ("pigtailed") of all valley systems incised into the Paleozoic bedrock in southeastern Minnesota. Downstream from the stop, for about the next 26 km (15 mi), the meander loops become broader and more widely spaced. Most tributary valleys from this stop to the Mississippi River, with the exception of Rush Creek, do not exhibit "pigtail" shapes.

Two distinct units are exposed in the north and west walls of the sand pit. Most of the exposure consists of clean sand with some interbedded gravel. It is well sorted, highly cross-bedded, and most of the pebbles are subrounded to rounded. Overlying this unit is an unbedded, poorly sorted, pebbly sand in which a soil has formed. Judging from its thick, black A horizon, the soil probably formed under prairie conditions, possibly during the early Holocene. There is no loess cap on this part of the terrace.

The 1- to 2-mm sand fraction is composed mostly of glacial erratics with lesser amounts of Paleozoic clasts, and possibly some Ostrander or Cretaceous grains. It is similar to the 1- to 2-mm sand fraction from the Whitewater terrace (Stop 4), although at this stop, the sand contains more dolomite.

Discussion. The surface of the terrace rises to the north and west, terminating at the valley wall. A well about 0.3 km (0.25 mi) northwest of the stop and about 12 m (40 ft) higher in elevation penetrated 38 m (125 ft) of sand with some gravel in the lower 10 m (30 ft) (Plate 1). A similar sequence on the south side of the valley has been documented by cuttings samples from the South Rushford municipal well (Plate 1).

1. Why is a loess cap not present on top of the sand at Stop 9? Was loess ever deposited at this site? We do not know if loess exists closer to the main valley wall on the north side, but no loess was encountered in the South Rushford municipal well.

2. When did the soil at the top of the sand form? If a loess cap once existed, the soil would postdate the loess, unless the soil is pre-late Wisconsinan.

3. Is the sand and gravel exposed at this stop a primary outwash deposit, or is it reworked earlier material?

Thick accumulations of sediment greater than 30 m (100 ft) occupy the Root River valley upstream for about 20 km (12 mi) to Lanesboro. At
Figure 1. Stop #9—sand pit in terrace west of Rushford along Minnesota Highway 16.
Lanesboro, the valley does not breach the Prairie du Chien, and the river flows directly on the Oneota Dolomite. From Lanesboro to the headwaters, sediments in the valley vary in thickness but generally appear to be less than 10 m (30 ft). Terrace remnants are evident in parts of the valley (Plate 1).

4. Do valleys that are deeply entrenched below the Prairie du Chien act as sediment traps, collecting material washing down the valley? Would backflooding from the Mississippi River have caused aggradation by granular material?

We believe that the Root River valley was one of the main channels for outwash during pre-Wisconsinan time. This is evidenced by its "pigtailed" morphology and by thick accumulations of glacially derived sand and gravel, especially below the point where the Prairie du Chien is breached.

5. Does the lowest downstream meander mark the point on the Prairie du Chien plateau where it was first breached during the Pleistocene?

6. Does the sequence of valley fills represent all of the episodes of deposition during the Pleistocene?

7. What do the thick deposits of silt or clay overlying the bedrock surface near the mouth of the Root River represent? These gray clays appear in wells that are not positioned over the centers of the valley. How do they relate to outwash deposition?
STOP #10 ROAD CUT SOUTH OF HOKAH ALONG HOUSTON COUNTY ROAD 18

This stop provides a unique view of the weathered surface of the Prairie du Chien plateau in the unglaciated portion of southeastern Minnesota (Fig. 1). Most of the roads in this area skirt the ends of ridges and follow the topography down to a valley floor. As a result, few exposures exist which provide any large-scale cross section of the unconsolidated deposits which either mantle the karsted Prairie du Chien plateau or fill solution cavities. At this stop, a county road has recently been widened and straightened by transversely cutting through a ridge top, thereby exposing the entire sequence so that thicknesses and stratigraphic relationships may be observed. This road cut was only discovered this spring, and no time has been available to thoroughly measure and describe the section. As a result, the following discussion can only point out features and ask questions based on a very sketchy examination of this exposure.

The Prairie du Chien plateau in this area is deeply dissected by tributary drainage, either eastward directly into the Mississippi River valley or northward into the Root River valley (Fig. 1). The loess cap, which increases in thickness toward the crest of the ridge, is the only Pleistocene deposit known to be present. No glacial erratics have yet been observed in any of the other materials exposed at this stop. This supports the concept that a small portion of extreme southeastern Minnesota either was never glaciated or at least no longer contains any glacially derived deposits other than loess.

The contact between the loess and all underlying materials is generally planar, except over some sinkhole fillings where the loess abruptly increases in thickness, and the contact becomes irregular. At the highest elevations on this ridge, the thickness of the loess cap would probably exceed 5 m (15 ft) if the bedrock surface and mantle of other unconsolidated deposits remain fairly constant.

Both formations of the Prairie du Chien (Stop 1, Fig. 2) are exposed in the cut uphill from the bridge. The contact between the Oneota Dolomite and the underlying Jordan Sandstone is exposed along the curve downhill from the bridge. Deep solution weathering of both the Oneota and the Shakopee is apparent, and slopewash, consisting of reddish-brown sediment, makes identification of their contact difficult to distinguish. County personnel have stated that excavation in the Prairie du Chien did not encounter totally unweathered bedrock, even at the deepest portions of the road cut.

The contact between the Oneota and the Shakopee is placed at the first appearance of the massive, cross-bedded New Richmond Sandstone Member of the Shakopee. This contact is best exposed on the west side of the road, but is interrupted by sinkhole fillings and is covered by slopewash. The New Richmond should be about 10 m (30 ft) thick, with the remainder of the bedrock section consisting of the Willow River Member of the Shakopee. The Willow River is almost completely covered by loess and red sediment. Its presence is documented by cobbles and boulders of sandy dolomite which weather out of the exposure uphill from the New Richmond.
Figure 1. Stop #10—road cut southeast of Hokah along Houston County Road.
The most noticeable aspects of this stop are the red-brown to yellow-brown, poorly cemented deposits, which cover the weathered surface of the Prairie du Chien or which fill sinkholes or other solution features. While their color remains relatively similar, their composition varies from pure clay to unsorted mixtures of sand, silt and cobbles. The source material for these sediments is thought to be reworked local bedrock types or bedrock residuum. These deposits generally exhibit some degree of bedding or evidence of placement by slumping. Sinkhole fillings are roughly wedge shaped and commonly contain large blocks of New Richmond Sandstone in addition to sandy material. The sinks are filled to the base of the loess and presumably were filled prior to loess deposition. The thickening of the loess cap over closely spaced sink fills indicates that the local topography may have been marked by sinkhole depressions prior to its burial.

Horizontal solution cavities within the Oneota trend roughly perpendicular to the filled sinkholes and appear to be packed with materials of slightly different composition. Sediments in them are primarily clay which may exhibit bedding. Coarse fragments of chert and sandstone, common to sinkhole fillings, are generally absent. At least one filled solution cavity is truncated by a filled sinkhole, which would suggest that cavity filling also pre-dated loess deposition.

Near the highest elevations in the cut, unbedded gray, noncherty clay covers red-brown, sandy sediment containing cobbles of Willow River Dolomite. The loess immediately above this clay is black, and this coloration appears to be laterally persistent throughout this portion of the road cut.

Discussion. This exposure has yet to be thoroughly studied, and any discussion of its relationship to the history of the Mississippi River valley would be speculative at best. Nevertheless, questions concerning methods for its study and the stratigraphic relationship already observed are pertinent.

Reddish-colored sediment associated with carbonate bedrock in the Upper Mississippi River valley has frequently been assumed to be terra rossa. Other stops have shown it to be glacial till or to be reworked into colluvial or alluvial deposits.

1. Is terra rossa present at this exposure?

2. What criteria should be incorporated into a useful definition of the term terra rossa? Could designating type localities for bedrock residuum materials serve as a guide for future investigations in the Upper Mississippi River valley?

3. Does any regional similarity exist between the red-brown materials which have been transported prior to their deposition onto carbonate bedrock plateaus? If so, should formational status be assigned to them?

If this portion of southeastern Minnesota was never glaciated, then a mechanism must be proposed to account for the deep dissection of the Prairie du Chien plateau. No nearby "pigtailed valley" segments exist
whose shapes have been discussed as being caused by the concentrated discharge of meltwater (Stop 7).

4. Bedrock valleys trend toward the Mississippi River valley and the Root River valley from the ridge where this stop is located. Did these drainage patterns develop at the same time? If so, where did the water come from to carve such deep channels radiating from such a small headwater area?

The origin of the gray clay below the loess and above red-brown sediment is unknown. If it were derived from terra rossa, the iron must have been reduced to account for its gray color.

5. Is this gray clay an old sediment dating back to a time when the Prairie du Chien plateau was not as deeply dissected as today? If so, where was the source for the clay, and how was it deposited?

6. What mechanism has caused the loess, which immediately overlies the gray clay, to turn black? Is this a paleosol? If so, why would an A horizon develop in the loess and not at the top of the clay? Why isn't the loess which overlies reddish-brown sediment colored black?

The age(s) of the solution weathering exhibited by the Prairie du Chien Group at this stop is also unknown. The high degree of karstification would suggest that dissolution was active prior to downcutting of the Mississippi River valley, although vadose dissolution may have also occurred. However, the filling of solution features with non-glacially derived sediment must be considered in any scenario involving vadose dissolution.

7. Did the infilling of sinkholes and solution cavities predate the downcutting of the Mississippi River valley? What relationship would have existed between the process of infilling and the position of the St. Peter Sandstone escarpment (Stop 5)?
LONG AGO... THE GEOLOGY GODS HAD SOME FUN

"LET'S REALLY CONFUSE THEM AND MAKE IT APPEAR THAT THE MISSISSIPPI RIVER REALLY FLOWED UPHILL!"

[Cartoon image of gods messing with the Mississippi River]
"Sven, we'd better go up nort for more... they're selling like hot lefse!"

How glacial erratics were really brought to southeastern Minnesota.
HOW THE MISSISSIPPI RIVER WAS NAMED
BY EARLY SETTLERS

"AH... SURE I THINK WE HAD BETTER KEEP CALLING IT "MISSISSIPPI RIFFER!""
"This ancient document confirms that glacial erratics were brought to southeastern Minnesota by my ancestors!"
Pleistocene geology and evolution of the Upper Mississippi valley.