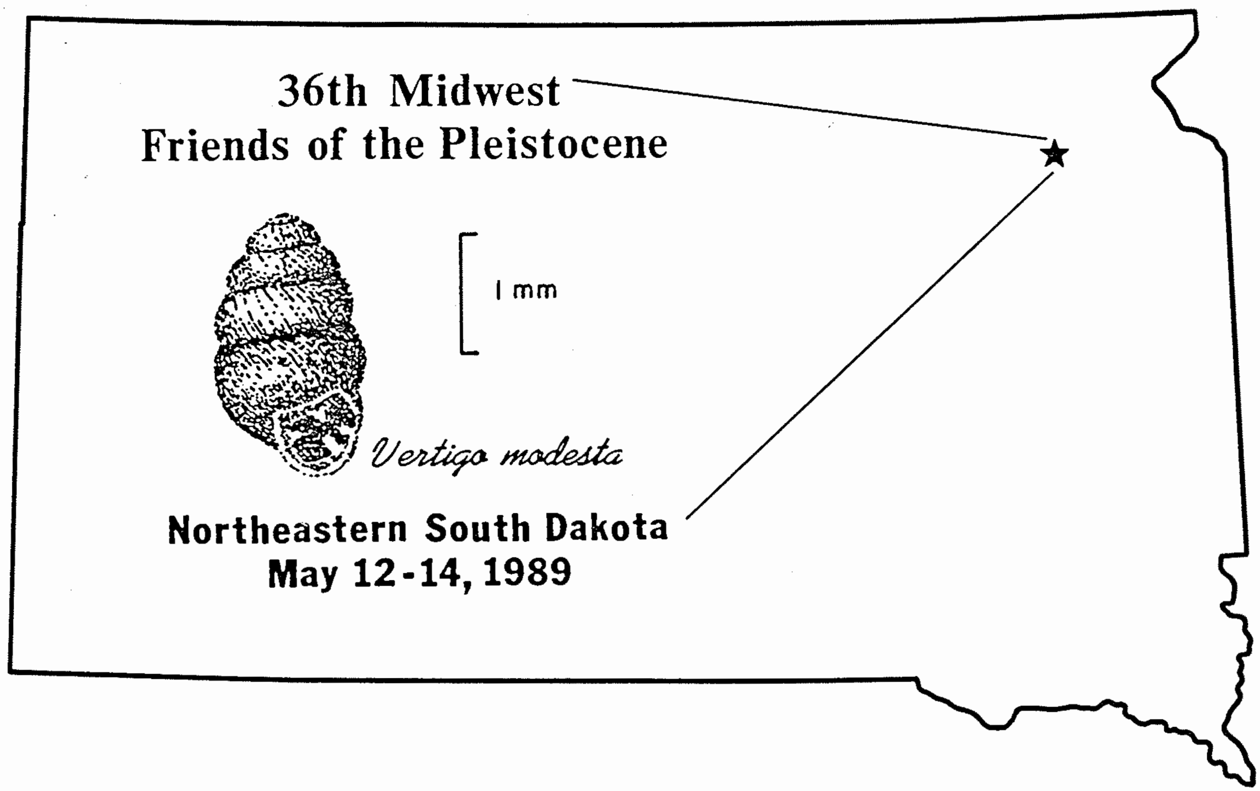
Guidebook No. 3

Quaternary Geology of Northeastern South Dakota



Edited by Jay P. Gilbertson

South Dakota Geological Survey
Vermillion, South Dakota

1989

STATE OF SOUTH DAKOTA
George S. Mickelson, Governor

DEPARTMENT OF WATER AND NATURAL RESOURCES
John J. Smith, Secretary

DIVISION OF GEOLOGICAL SURVEY
Merlin J. Tipton, State Geologist

GUIDEBOOK 3

QUATERNARY GEOLOGY OF NORTHEASTERN SOUTH DAKOTA

Jay P. Gilbertson, Editor

Science Center
University of South Dakota
Vermillion, South Dakota

1989

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3	1952	Western Illinois and Eastern Iowa	P. R. Shaffer and H. W. Scholtes
U	1952	Southwestern Ohio	R. P. Goldthwait
U	1953	Northeastern Wisconsin	F. T. Thwaites
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U	1956	Northwestern Lower Michigan ..	J. H. Zumberge and others
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U - Unnumbered

ACKNOWLEDGEMENTS

Field and laboratory work reported in this guidebook was conducted under the auspices of the Codington, Grant, Brookings, and Kingsbury County investigations. These investigations were supported by the South Dakota Department of Water and Natural Resources, the U.S. Geological Survey, the East Dakota Water Development District, and the respective counties. A number of people contributed to many phases of the studies, and their contributions are greatly appreciated. Of note were field assistants Suzanne Kairo, Susan Jensema, and Christopher O'Neill, and South Dakota Geological Survey drillers, E. Thomas McCue and Dennis Iverson.

Throughout the course of these studies, as well as during this field trip, ready access to key exposures has been provided by numerous individual landowners and quarry operators. Listed below are those who properties will be visited during this meeting: Lester Rethke, Carl Loraff, John Nordick, Erma Adelman, Dakota Granite Company, Jerry Thurman, and Devon and Marlys Reeves.

Merlin Tipton, Cleo Christensen, Charles Matsch, Martin Jarrett, and Richard Hammond participated in fruitful discussions on various topics presented herein. Numerous individuals at the South Dakota Geological Survey reviewed draft copies of this guidebook and their comments and suggestions are appreciated. Colleen Odenbrett, Dennis Johnson, Beverly Barkosky, and David Kahle prepared the manuscript and illustrations. Martin Jarrett, Layne Schulz, George Duchossois, Louis Frykman, and Dennis Tomhave participated in the planning and execution of the logistical aspects of this trip.

QUATERNARY STRATIGRAPHY OF NORTHEASTERN SOUTH DAKOTA

By
Jay P. Gilbertson and J. D. Lehr

Introduction

The Quaternary history of northeastern South Dakota is one of repeated glacial and nonglacial events. Ice sheets that covered all or part of the region at various times have left behind an impressive accumulation of a variety of glacial sediments. Nonglacial events (either interstadial or interglacial) are marked by unconformities in the stratigraphic sequence and evidence of subaerial weathering.

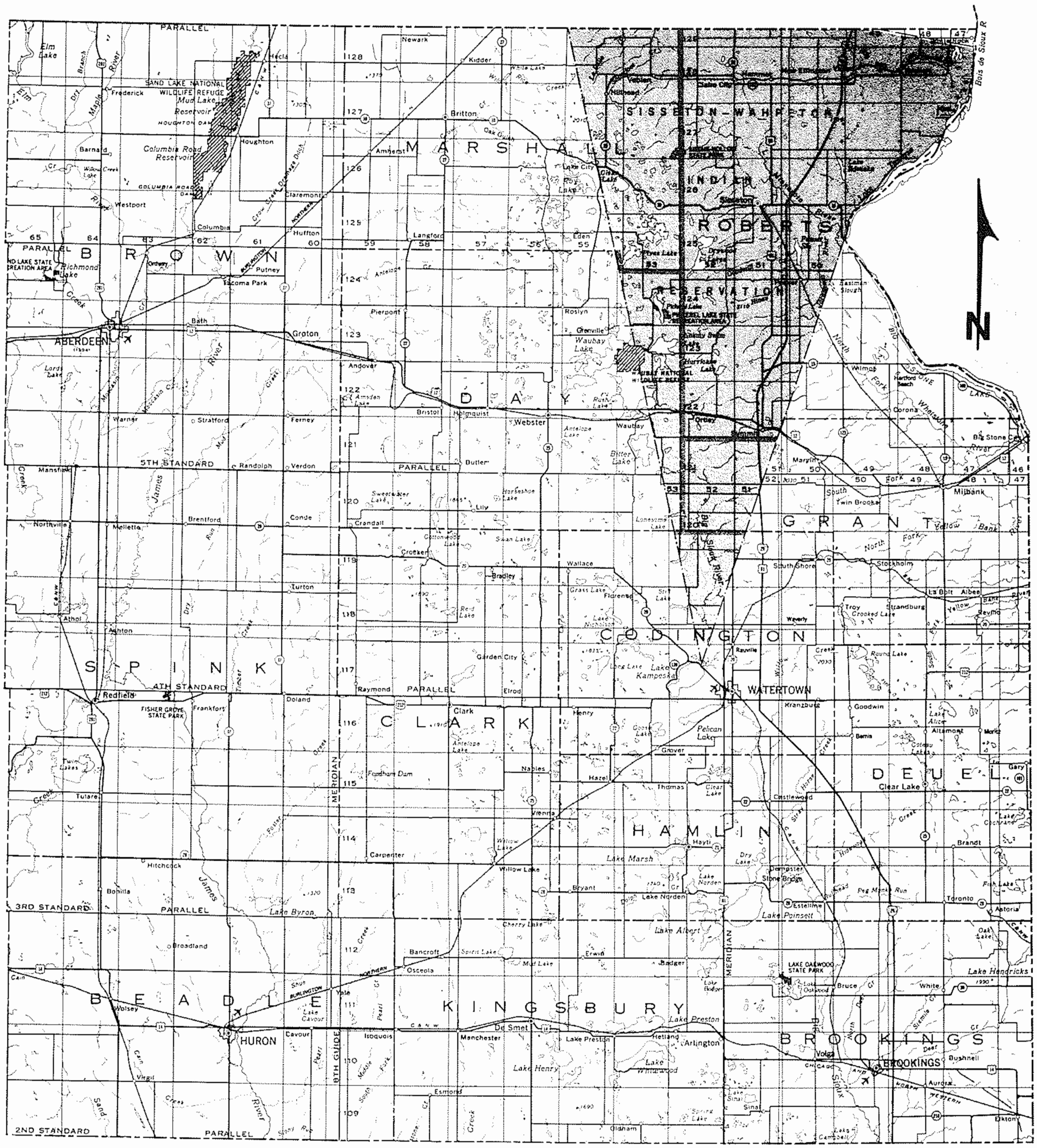
Physiography

Topographically, the area is dominated by the Coteau des Prairies, a wedge-shaped highland that starts at the North Dakota border and can be traced south to where it eventually merges with generally higher ground in southwestern Minnesota and northwestern Iowa (figs. 1 and 2). It is flanked by two lowlands, the James River basin to the west and the Minnesota River and Red River valleys to the east. An idealized topographic cross section through the Coteau des Prairies (fig. 3) shows a mild asymmetry to the highland, with the maximum relief along the eastern edge.

Three rivers in the region are responsible for most of the drainage. The Minnesota River and its tributaries drains the eastern lowlands and the adjacent flank of the Coteau des Prairie. The James River basin receives runoff from the western slope of the Coteau. The Big Sioux River flows down the center of the Coteau des Prairies, although there are significant areas on the highland without external drainage. All three rivers are part of the Mississippi River system. The Bois de Sioux River and other small streams in the extreme northeastern corner of South Dakota lead to the Red River, which ultimately leads to Hudson Bay.

Previous Investigations

Various aspects of the Quaternary geology of northeastern South Dakota have come under investigation over the past 100 or more years. Results of many of the earlier state and federal studies were compiled in numerous summary publications that included all or part of the state. Of particular note are works by Chamberlin (1883), in which the terminal position of the late Wisconsin ice advance is described, and Leverett (1932), where the numerous late Wisconsin moraines are described. The last major report of this type (Flint, 1955) described the Quaternary geology and history of eastern South Dakota. For a more detailed summary of earlier investigations, the reader is referred to Flint (1955).



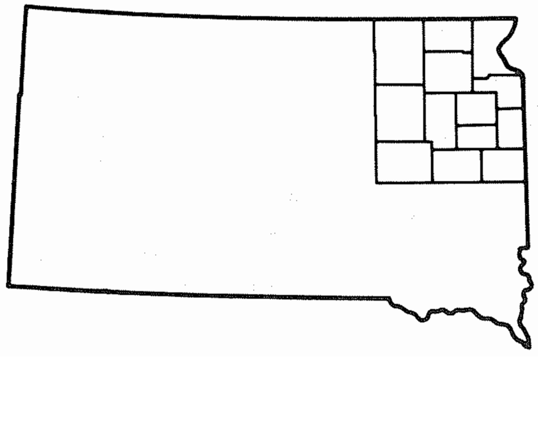
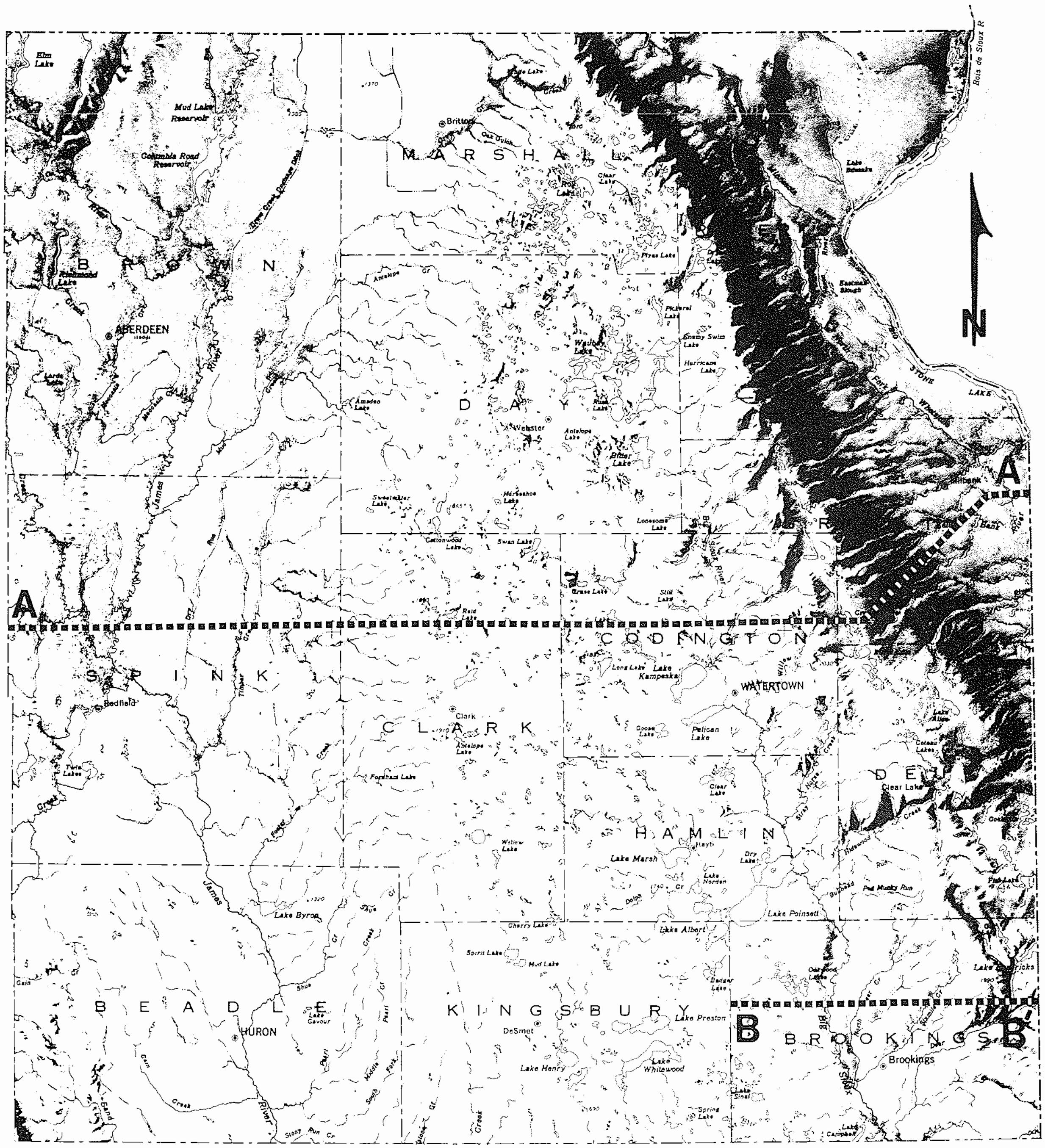


Figure I. Physiographic map of northeastern South Dakota.



Stratigraphic cross section. See figure 3 for A-A′ and figure 5 for B-B′.

0 — 36 MILES

Figure 2. Shaded-relief map of northeastern South Dakota.

By the late 1950's, most of the investigations into the glacial history of South Dakota were being conducted by the South Dakota Geological Survey. Growing interest in the delineation and proper management of the state's ground-water resources was allowing for an increased number of studies of the shallow glacial aquifers in the eastern half of the state. As an outgrowth of these hydrologic studies, the Survey produced a series of surficial geologic maps of various 15-minute quadrangles. Maps in this series that cover segments of the northeastern part of the state are in the James River basin (Steece, 1967a, b) and the upper Big Sioux River valley (Lee, 1958a, b; Steece, 1958a, b, c; Tipton 1958a, b, c, d; and Lee, 1960a, b). The results and interpretations developed from these studies were presented at the 1960 Midwest Friends of the Pleistocene Field Conference (Steece and others, 1960).

In 1959, in conjunction with the U.S. Geological Survey, the South Dakota Geological Survey began a series of county wide geologic and hydrologic investigations. These studies involved not only the mapping and evaluation of surficial deposits, but also included a systematic program of drilling test holes to bedrock. These studies, in addition to providing a better understanding of the nature and extent of major aquifers, allowed for the examination and description of the Quaternary sediments not exposed at the land surface.

County wide geologic investigations have been completed for most of the counties in northeastern South Dakota. These include Beadle (Hedges, 1968), Brown (Leap, 1986), Clark (Christensen, 1987), Day (Leap, 1988), Deuel and Hamlin (Beissel and Gilbertson, 1987), and Marshall (Koch, 1975). Field studies have been completed in Codington and Grant (Gilbertson, in preparation) and Brookings and Kingsbury (Jarrett and others, in preparation). An investigation of Spink County began in 1988 and work should start in Roberts County in the near future. Preliminary results of some of the earlier investigations were included in a guidebook compiled by Matsch and others (1972).

Regional Stratigraphy

Although a considerable amount of basic data has been collected in the course of the various county study investigations, only a limited number of detailed examinations of the Quaternary stratigraphy of the region have been attempted. As a consequence, there are few formally defined stratigraphic units in northeastern South Dakota. Where appropriate, nomenclature from adjacent states (Minnesota and North Dakota) has been used to describe lithologically similar deposits.

Quaternary units that have been identified only in the subsurface are referred to as drift complexes. Although they are most likely composed of material from more than one ice advance, the various drift complexes represent units that can be traced across

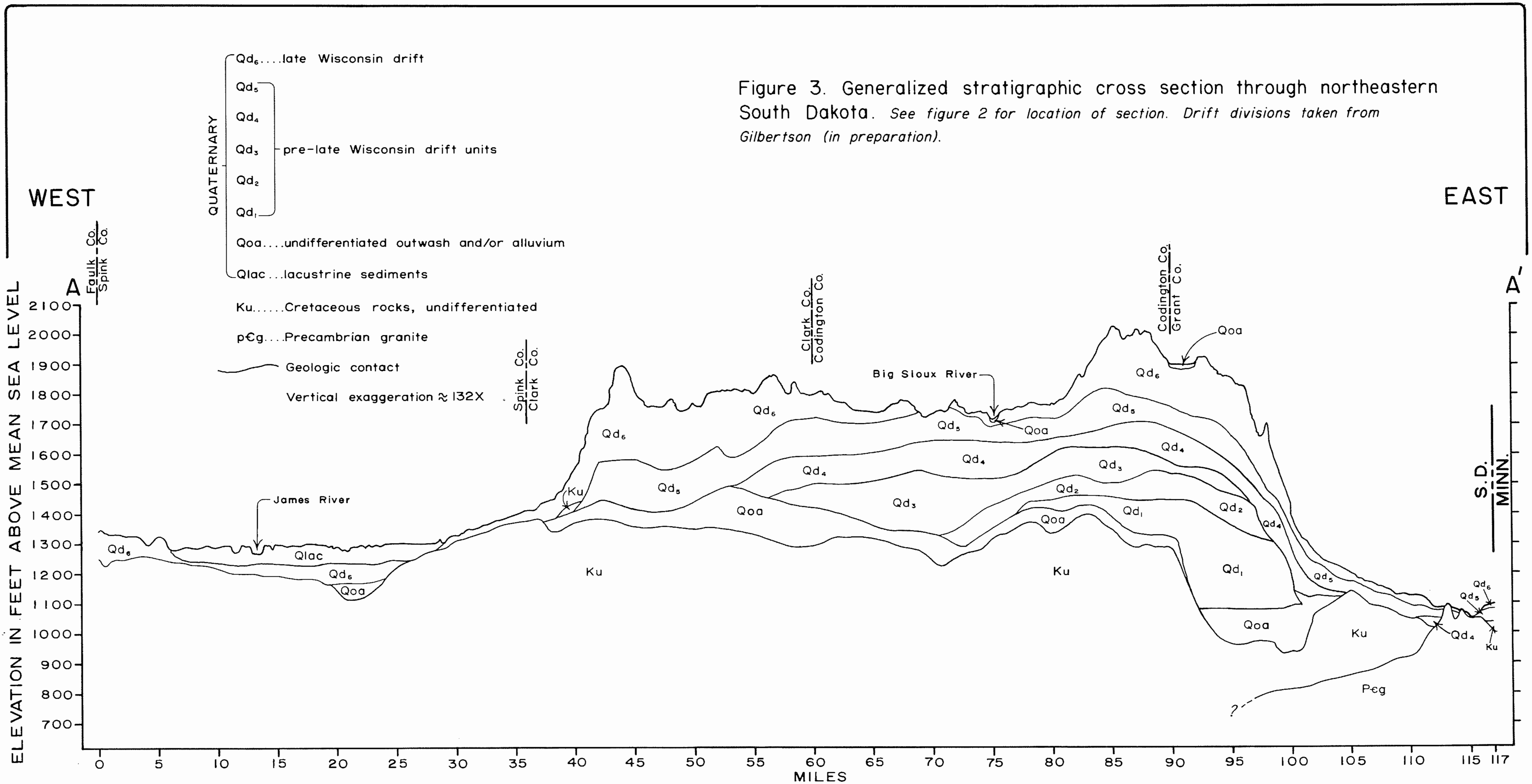


Figure 3. Generalized stratigraphic cross section through northeastern South Dakota. *See figure 2 for location of section. Drift divisions taken from Gilbertson (in preparation).*

several counties. All late Wisconsin deposits are included in Drift Complex 6, identified as Qd6 on figure 3, while pre-late Wisconsin units make up Drift Complexes 5 through 1 (Qd5 - Qd1).

Chronologic control on the various Quaternary deposits of South Dakota is limited by a relative paucity of material suitable for age determination. With the exception of a very well defined advance in the James River valley around 12,500 yr B.P. (Clayton and Moran, 1982), most of the age assignments presented herein are derived either from only a few absolute age determinations or from correlation with adjacent areas.

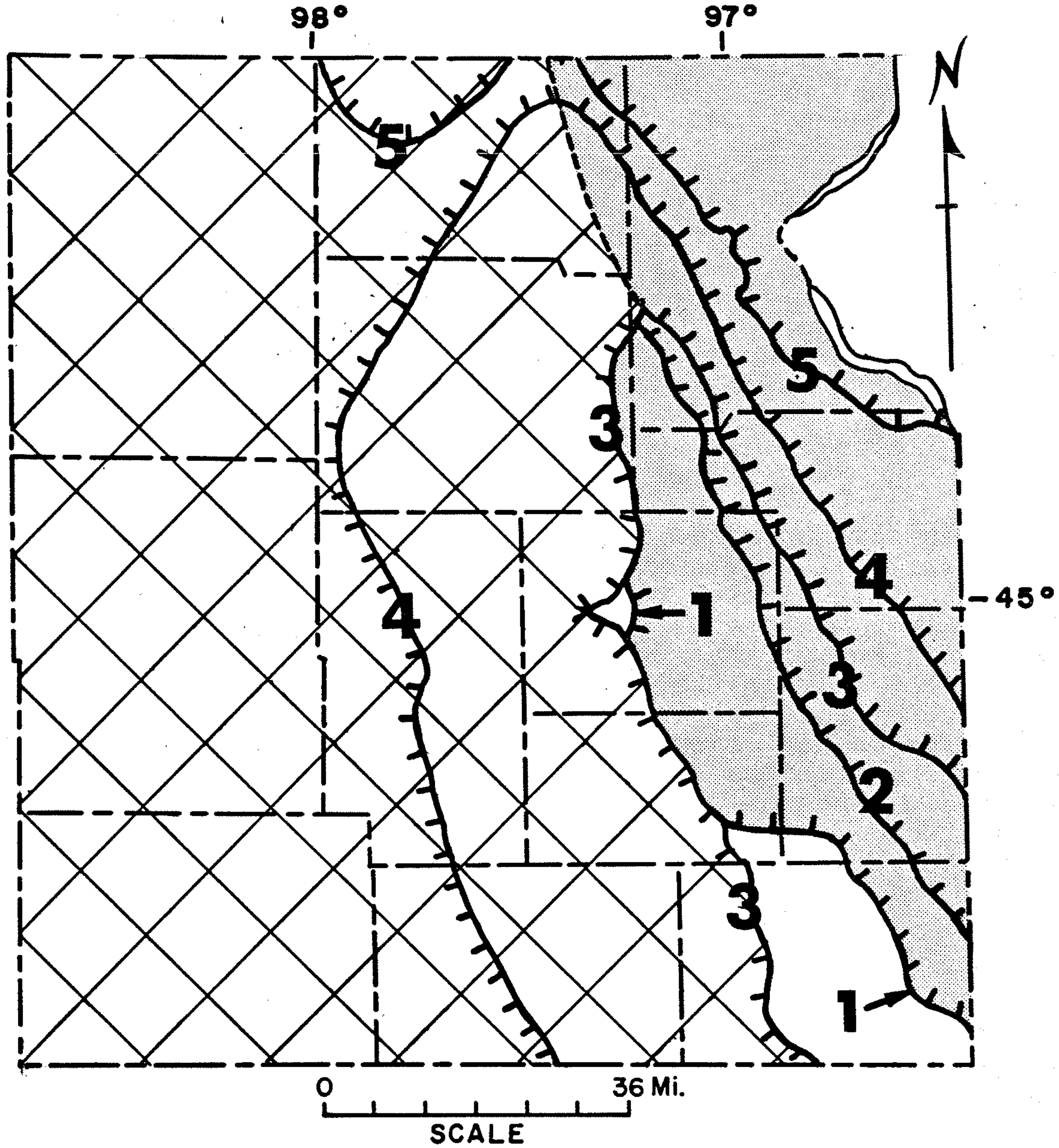
Pre-Late Wisconsin Deposits

Materials deposited prior to the late Wisconsin can be found over nearly all of northeastern South Dakota, although surface exposures are limited to the central and lower reaches of the Big Sioux River basin and isolated stream and river valleys along the eastern flank of the Coteau des Prairies. These older deposits are absent only in the James River valley, where late Wisconsin James lobe drift rests directly on bedrock. It is most likely that erosion has removed older materials from this area, as they are present to the south and southwest of this area. Pre-late Wisconsin deposits identified on the Coteau des Prairies and those found in the Minnesota River valley will be discussed separately.

Coteau des Prairies

Pre-late Wisconsin glacial sediments constitute the bulk of the Coteau des Prairies (fig 3). Over most of the highland these deposits average over 400 feet in thickness, and in places may exceed 700 feet. No detailed stratigraphic study of these materials has been attempted, but most of the tills encountered in this sequence appear to be lithologically similar, normally gray to dark-gray, pebbly tills. The sequence has been subdivided on the basis of certain gross characteristics, particularly the presence of extensive oxidized zones, outwash bodies, and geophysical log signals.

The term "Brookings till plain" was proposed by Lehr and Gilbertson (1988) for the surface expression of pre-late Wisconsin units in the Big Sioux River basin in northeastern South Dakota (fig. 4). It is roughly equivalent to the area mapped as Iowan by Flint (1955) and Lee (1958a, b; 1960a, b). A pronounced topographic break and a shift of linear features in the landscape separate the Brookings till plain from late Wisconsin materials. A thick, composite zone of oxidized till is characteristic of this drift complex, and this can be traced for a considerable distance under younger deposits (Qpwt (ox) on fig. 5, Qd5 on fig. 3).



James Lobe	#	Des Moines Lobe
Oakes	5	Big Stone
DeSmet	4	Gary
Dakota	3	Altamont
–	2	Bemis
–	1	Still Lake

Pre-late Wisconsin drift (Brookings till plain)

Figure 4. Approximate late Wisconsin end moraine positions in northeastern South Dakota.

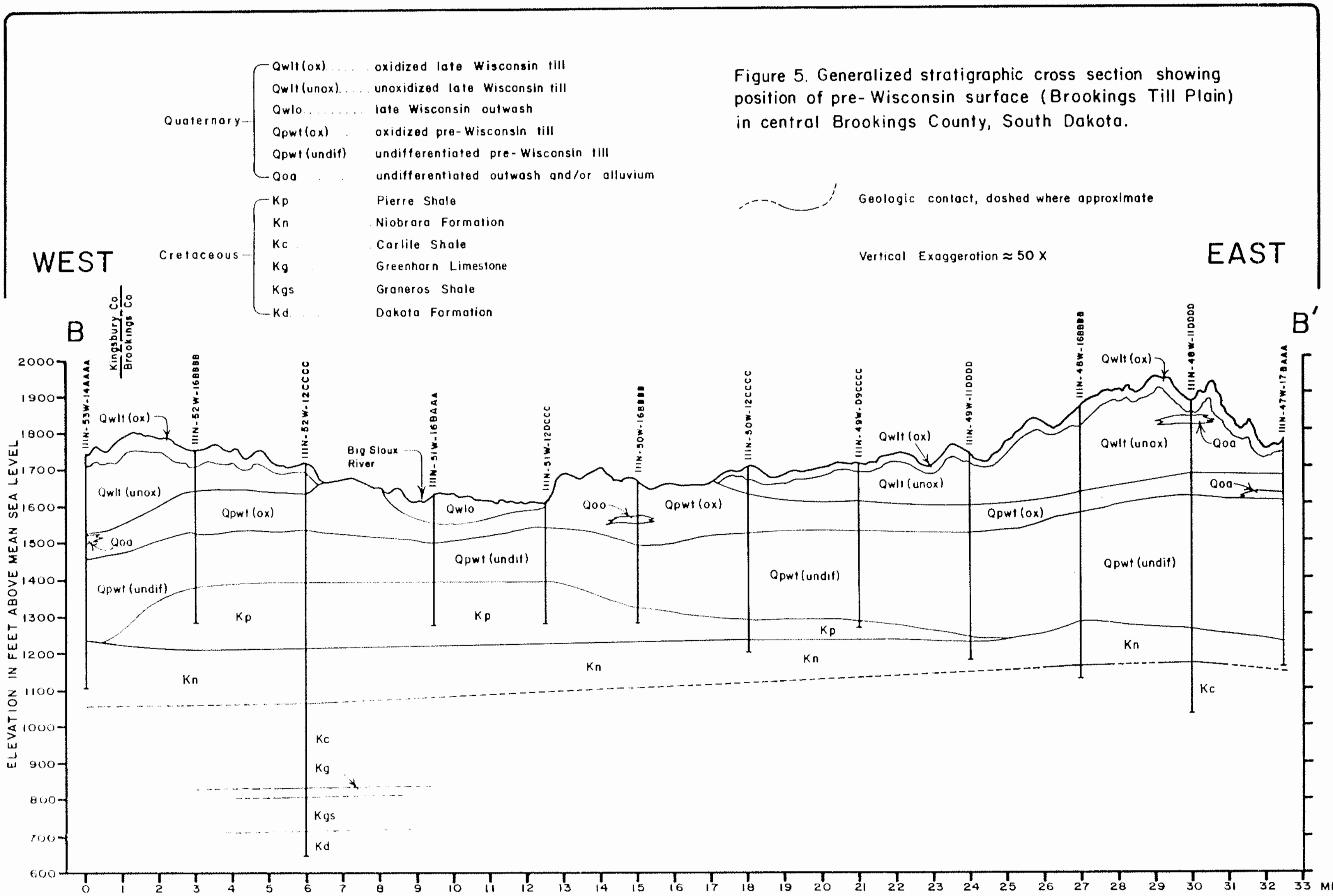


Figure 5. Generalized stratigraphic cross section showing position of pre-Wisconsin surface (Brookings Till Plain) in central Brookings County, South Dakota.

Older drift units (Qd4 thru Qd1) have only been identified in test holes. As with the other complexes shown on figure 3, they are undoubtedly composites of several periods of glacial activity.

The exact age of these older units is unknown. Several infinite radiocarbon ages have been produced by wood samples recovered from within the older complexes, indicating at least a pre-late Wisconsin age. Geophysical logs from numerous test holes in the region suggest the presence of several buried volcanic ash beds, the youngest of which is most likely the 610,000 year old Pearlette "O." In western and central Codington County, several ash(?) spikes appear to be associated with the top of drift unit 3 (Qd3 on fig. 3). By inference then, a considerable portion of the older drifts that make up the core of the Coteau des Prairies may date from the early Pleistocene, and possibly the Pliocene, similar to many of the older drifts in western Iowa (Hallberg, 1986).

Minnesota River Valley

In extreme northeastern South Dakota, a sequence of pre-late Wisconsin sediments are found along the tributaries of the Minnesota River, particularly the Whetstone and Yellow Bank Rivers. Three separate tills have been identified beneath the late Wisconsin New Ulm till; in descending order they are the Granite Falls, Hawk Creek, and Whetstone tills (Rutford and Matsch, 1972; Gilbertson and Jensema, 1987). A nonglacial unit, informally referred to as the "gastropod silts," is sometimes found separating the lowermost tills. Figure 6 shows the relative position of the various units. The three older tills can be distinguished quite easily using the lithology of the coarse-sand fraction.

The gastropod silts contain a variety of organic materials that may be useful in interpreting the paleoclimate of the area during a segment of pre-late Wisconsin time. Animal remains recovered to date include gastropods, ostracodes, insect fragments, and microtine rodents. Small pieces of plant material are quite common, particularly at the top of the sequence. The beds have also been a source for numerous large wood (conifer) fragments, as well as pollen.

Age determinations have been made on several samples of organic material from the gastropod silts. Several wood fragments from the unit have yielded infinite radiocarbon ages (>56,000 yr B.P., QL-4151; >56,000 yr B.P., QL-4152), as did a bulk sample of the organic horizon at the top of the unit (>25,000 yr B.P., GX-2734). A wood fragment recovered from the base of the overlying Hawk Creek till, which likely was derived from the silts, produced an age of >32,000 yr B.P. (GX-13,775). An amino-acid racemization analysis of several small gastropods (<u>Pupilla muscorum</u>) resulted in an age estimate of 140,000 ± 70,000 years.

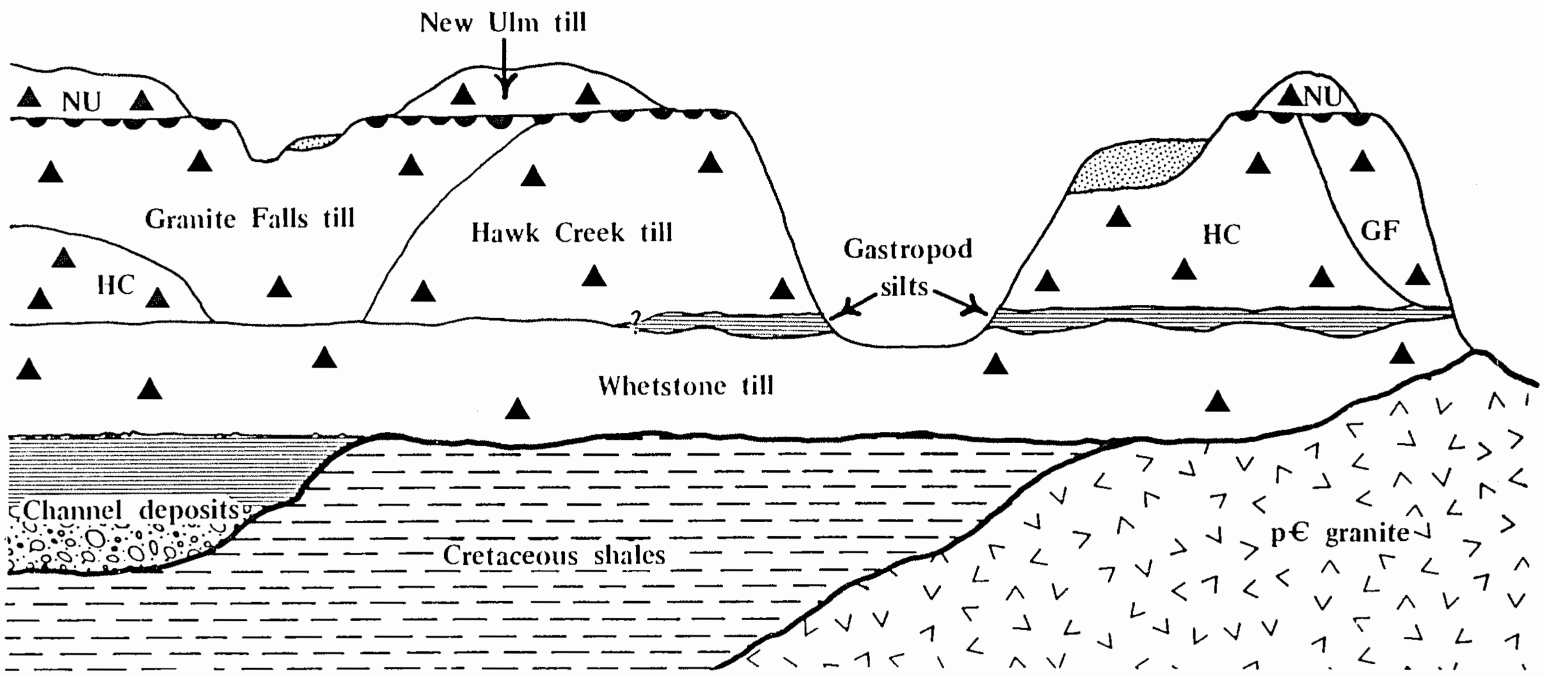


Figure 6. Generalized stratigraphic section showing the relative position of principle Quaternary units in northeastern Grant County, South Dakota.

Ages of the older units found in the Minnesota River valley are as yet poorly understood. The stratigraphic position of many of the materials on which age determinations have been made is unclear, and ages assigned to the units have varied. Matsch (1971), in the original description of the Granite Falls and Hawk Creek tills, suggested that they were Wisconsin in age. In a recent summary, Matsch and Schneider (1986) assigned an Illinoian age to the Granite Falls till, and a pre-Illinoian age to the Hawk Creek and older tills. If the limited chronologic information from this area is valid, then the gastropod silts (and the Hawk Creek till) were deposited during late Illinoian time. The absence of any clear weathering horizon in the Whetstone till suggests that it may also have been deposited during this time.

The age of the Granite Falls till remains unclear. It is lithologically dissimilar to any of the tills of known late Wisconsin age in the area, and is found stratigraphically above the Hawk Creek till. It is probably late Illinoian in age, although the possibility of an early Wisconsin age cannot be completely ignored.

Late Wisconsin Deposits

Late Wisconsin units in northeastern South Dakota are separated into two chronostratigraphic divisions, based on topographic expression and a limited number of radiocarbon age determinations. Both divisions fall roughly within the boundaries of the Woodfordian substage of Illinois (Frye and others, 1965) and the terms early Woodfordian and late Woodfordian will be used to describe them. The qualified use of these terms is acceptable, and certainly preferable to the creation of local chronostratigraphic units based on limited radiometric control.

Early Woodfordian

Surface exposures of early Woodfordian drift are restricted to the drainage basin of the upper Big Sioux River, in the area between margins 1 and 2 shown on figure 4. Recognized materials of this age are believed to have been deposited by ice occupying the Minnesota River valley (the Des Moines lobe). No comparable James lobe sediments have been identified. With minor modifications of the areal extent, this is the Tazewell till of Flint (1955) and the Toronto till plain of Lehr and Gilbertson (1988).

The outer limit of these deposits is commonly marked by either an abrupt change in orientation of linear features (northwest-southeast vs. northeast-southwest for the Brookings surface) or by heads of outwash. In central Codington County and southern Deuel County, possible end moraine segments (Still Lake moraine) related to this interval have been identified. Behind the margin, the landscape is fairly mature, with only a limited number of undrained depressions. The depth of surface oxidation rarely exceeds 10 meters.

Analyses of till from the Toronto till plain (the Toronto till) indicate that it is texturally similar to the younger New Ulm till (a clay loam), and also contains a significant percentage of Late Cretaceous lithologies in the 1 to 2 mm sand fraction. However, although dominated by shale fragments, the Toronto till also contains dirty carbonates and sandstones in the coarse-sand fraction, a useful tool in separating it from the New Ulm. Matsch (1971) identified a similar unit, the extra-morainic, shale-bearing till in southwestern Minnesota.

Radiocarbon ages of wood recovered from this material span nearly 10,000 years. Two samples recovered from the base of the surface drift in eastern Hamlin County yielded ages of 22,900 ± 1,000 yr B.P. (GX-3539) and 26,150 +3,000/-2,000 yr B.P. (GX-2864) (Beissel and Gilbertson, 1987). An age of 29,910 ± 1,160 yr B.P. (GX-14675) was determined from a sample recovered recently from an exposure of Toronto till in southwestern Grant County. Wood found in extreme northeastern Grant County produced an age of 20,670 +1,500/-1,000 (GX-2741). Found beneath a glacially-disturbed block of Hawk Creek till, this material is believed to have been emplaced during this time.

Late Woodfordian

Late Woodfordian drift units cover most of northeastern South Dakota. These materials were deposited by two separate lobes of ice, the Des Moines lobe in the Minnesota River valley and the James lobe in the James River basin. Prominent end moraines mark the limits of successive advances of the two ice lobes (margins 2-5 on fig. 4). An immature landscape, characterized by poorly-developed drainages and abundant ice-stagnation features readily distinguish these materials from older deposits, particularly on the Coteau des Prairies.

Tills deposited by either lobe are lithologically quite similar. Both are predominantly pebbly clay loams, and contain a high percentage of Late Cretaceous shales in the coarse sand fraction. The New Ulm till (Matsch, 1971) was deposited by the Des Moines lobe in the Minnesota River valley and along the eastern flank of the Coteau des Prairies. It is distinguished from the early Woodfordian Toronto till by the lack of nonshale lithologies in the Late Cretaceous coarse sand fraction. It is correlative with the Dows Formation in Iowa (Kemmis and others, 1981).

Drift deposited by the late Woodfordian James lobe has not been formally (or informally) described. In South Dakota Geological Survey publications, it is referred to simply as late Wisconsin till (see for example Christensen, 1987; Leap, 1986). In geochemical a study of various glacial deposits in eastern South

Dakota, Searight and Moxon (1945) recognized two separate units, the Arlington and De Smet drifts. However, their separation was based primarily on geomorphic considerations rather than lithologic differences. The Arlington drift constituted that material found on the Coteau des Prairies between the Dakota and De Smet moraines (fig. 4). De Smet drift represented materials found behind the De Smet moraine, and as such is restricted mostly to the James River valley.

The base of the New Ulm till is marked by a one-stone thick, faceted boulder pavement. The faceted surfaces of the pavement stones are striated, with the striations consistently trending to the southeast. Initially described only along the Minnesota and Whetstone Rivers (Matsch, 1971; Rutford and Matsch, 1972), the pavement has now been recognized well up the eastern flank of the Coteau des Prairies. Where the striations are recognizable on these stones, they show no clear divergence from the overall trend to the southeast. A similar boulder pavement has also been described at the base of the late Woodfordian James lobe drift in isolated exposures (Hedges, 1968; Koch, 1975).

The origin of the boulder pavement is not clearly understood. Matsch (1971) speculated that the stone concentration was either the result of lodgement during deposition of the New Ulm till, or the product by subareal weathering on the pre-New Ulm surface. In most cases, the pavement is found separating the New Ulm till from older tills that contain similar clast lithologies, either the Granite Falls or Toronto. As such it is difficult to establish a clear source for the pavement stones. Also, no clear evidence of deformation has been found in the tills immediately adjacent to the stones.

Late Woodfordian materials were first deposited in northeastern South Dakota approximately 14,000 years ago (Matsch and others, 1972). At least four distinct ice advances took place during this time. For all but the earliest (Bemis) advance, nearly continuous end moraines from successively younger advances (Altamont/Dakota, Gary/De Smet, and Big Stone/Oakes) can be traced from east to west (fig. 4), suggesting that advances of the Des Moines lobe and the James lobe were approximately synchronous. To date no James lobe 'Bemis' moraine has been recognized. By about 11,600 yr B.P., the Big Stone and Oakes moraines were abandoned (Fenton and others, 1983) and South Dakota was no longer host to any active glacial ice.

Glacial Lakes

As the margin of the late Wisconsin glacier slowly retreated from the state, a significant portion of the meltwaters were ponded between the ice front and generally higher ground to the south. This resulted in the formation of a series of proglacial and ice-marginal lakes in the James River and Minnesota River lowlands. Glacial Lake Dakota and Lake Agassiz are the most prominent examples, but smaller areas of glaciolacustrine sediments can be found over much of the area. Initial lake formation may have taken place as early as 12,000 yr B.P., as the ice margins retreated from the Gary/De Smet moraines. Continued retreat of the ice margins into North Dakota and Canada eventually opened northern outlets for these meltwaters and the period of glaciolacustrine and related activity ceased around 9,500 yr B.P. (Fenton and others, 1983).

Holocene

With the retreat of active ice from the area and the demise of the large glacial lakes, sediment accumulation and landscape modification has proceeded at a considerably slower pace. Alluvial materials have accumulated in most of the major stream valleys as integrated drainage networks have slowly developed in the areas covered by late Wisconsin ice. Streams, originating on the Coteau des Prairies, have cut deep gullies along the flanks of this highland. Sediment fans are often found at the base of the steeper reaches of these streams (Jarrett, 1986). In the areas as yet without external drainage, small-scale sediment transfer (slope wash, creep, etc.) has resulted in basin filling and a general reduction in local relief.

Paleoecological studies of post-glacial sediments preserved in area lake basins have centered about two lakes, Pickerel Lake (Watts and Bright, 1968), located just to the north of Enemy Swim Lake, and Medicine Lake (Radle, 1981), located to the northwest of the city of Watertown. Using cores of lake sediments and studying fossil pollen, spores, seeds, leaves and mollusks, both studies indicate the presence of boreal forest existing at the time these ice-block lakes formed around 11,000 yr B.P. *Picea* sp. dominated this boreal environment, slowly giving way to *Betula* sp. (around 10,500 yr B.P.) and other deciduous trees as the climate became warmer and drier. Blue-stem prairie dominated the environment from 8,000 yr B.P. to 4,000 yr B.P. as the summers became hotter and drought more frequent. During this time the lakes became strongly alkaline, and water levels fluctuated markedly. In the last 4,000 years, the climate has remained much the same as we have today. Man's impact on the environment becomes evident around 100 yr B.P. with the sharp influx of *Ambrosia* sp., a good indicator of land clearance and cultivation.

GEOLOGIC ROAD LOG - SATURDAY, MAY 13, 1989

by
Jay Gilbertson, Martin Jarrett, and Layne Schulz

Note: Mileage in this guide is given first as cumulative miles, followed by the increments between entries.

The field trip route for today can be followed on figures 7 and 8. The route for Sunday is covered by figures 7, 9, and 10. These figures follow page 29.

0.0	0.0	Assemble in the NeSoDak parking lot at 7:30 a.m. and board buses for today's excursion.
0.6	0.6	Drive south on the peninsula road, bearing left at the substation, to the junction with Enemy Swim Lake Road (Day County Road 1).
0.8	0.2	Continue south on Enemy Swim Lake Road to the intersection with Bureau of Indian Affairs Road 500. Turn left (east). We are crossing over an area of low-relief stagnation moraine associated with the late Woodfordian James lobe advance in this area.
2.4	1.6	Proximal edge of the Dakota moraine.
3.0	0.6	Crest of the Dakota moraine. We pass through the moraine in a breach created by meltwater from the Des Moines lobe at the Altamont moraine position. For about the next 4 miles we will be crossing the northern end of the early Woodfordian Toronto till plain.
3.9	0.9	Leave Day County, enter Roberts County.
4.6	0.7	Cross a late Woodfordian drainage channel.
6.0	1.4	From this point it is possible to get a good view of the entire interlobate area and the encompassing moraines. The James lobe Dakota moraine, to the west, can be traced to its confluence with the moraines of the Des Moines lobe, about 8 miles north of here. From that point the more pronounced Altamont moraine can be followed to the south and east.
7.2	1.2	Cross onto the Des Moines lobe Bemis moraine. Note the low relief, yet still rugged,

		constructional topography as compared with the surface of the Toronto till plain.
7.4	0.2	Intersection with Roberts County Road 28. Turn right (south). The "crest" of the Bemis moraine is now to the right (west), and the Altamont moraine is to the east.
7.8	0.4	Leave the Bemis moraine and cross back onto the Toronto till plain.
8.4	0.4	Turn left (east) onto gravel road.
8.7	0.3	Cross back onto the Bemis moraine.
9.9	1.2	Turn right (south) at intersection.
10.9	1.0	At intersection, turn left (east) onto Roberts County Road 17.
		In the northeast corner of the intersection is an observation well (RB-81D) in a surficial aquifer. It is part of a network of over 1,550 monitoring wells maintained by the South Dakota Department of Water and Natural Resources Division of Water Rights. Data collected from these wells are used to more effectively allocate the state's ground-water resources.
13.0	2.1	Gravel pits flanking the road at this point expose the sorted sediments that blanket the moraines in this area. These sands and gravels are of generally poor quality and suitable only as road metal.
13.8	0.8	**STOP 1: TOP OF THE COTEAU DES PRAIRIES**. This will be a short, scenic stop. Refer to stop description on page 34.
		Continue east on Roberts County Road 17.
14.9	1.1	Intersection with former U.S. Highway 81. Continue east on State Highway 109.
15.9	1.0	Cross over Interstate 29. This area affords a good view off the eastern side of the Coteau.
17.1	1.2	At the sharp break in slope the road starts the final descent off the Coteau des Prairies and into the Whetstone/Minnesota River valley.
18.1	1.0	Intersection with gravel road. The elevation at this point is 1,428 feet. We have descended 632 feet in the last 4.3 miles. From here to the edge of the Big Stone Lake trench we will drop

another 300 feet in elevation, but will take 14 miles to do so.

For the next 7 miles we will be crossing over gently rolling, late Woodfordian ground moraine. The surface drift (New Ulm till) is rarely over 50 feet thick, and the base of the unit is commonly marked by a faceted boulder pavement.

19.5	1.4	Cross boundary of the Lake Traverse Indian Reservation.
20.8	1.3	Valley of small stream that drains off the flank of the Coteau.
22.8	2.0	Enter another stream valley that heads on the Coteau des Prairies.
23.2	0.4	As the road starts to rise out of the valley, one can observe faceted boulders emerging from near the top of the valley walls. These stones are part of the regional boulder pavement.
23.9	0.7	Enter town of Wilmot.
24.6	0.7	Enter the valley of the North Fork of the Whetstone River. The river formed as an ice-marginal drainage flowing along the front of the Des Moines lobe during the formation of the Big Stone moraine.
25.3	0.7	Leave river valley and move onto the Big Stone moraine. The moraine in this area is fairly wide and of generally low relief. Numerous small ridges impart a strong linear appearance to the surface. They may be annual(?) moraines deposited during a period of slow retreat of the ice front.
25.8	0.5	Intersection with Roberts County Road 4. The infamous Ike's Chicken Shack on beautiful Lake Traverse is 20 miles to the north. Continue east on Highway 15.
29.3	3.5	Minder National Waterfowl Production Area. An example of a practical use for "non-productive" farmland.
31.0	1.7	Big Stone Lake trench is visible to the east.
32.9	1.9	Gravel pit to the north is located in a terrace of uncertain origin. Its elevation (1,100 ft/335 m) suggests it may be related to Lake Milnor, a high-stage predecessor to Lake Agassiz.

33.6	0.7	Turn left (north) into Hartford Beach State Park.
33.9	0.3	Turn right at the fee booth.
34.0	0.1	Bear right at the fork in the road.
34.6	0.6	**STOP 2: BIG STONE LAKE AND GLACIAL RIVER WARREN**. This will be another short, scenic stop, with the added attraction of toilet facilities and refreshments. Refer to stop description on page 36.
		Retrace route to State Highway 109.
35.7	1.1	Turn left (east) onto State Highway 109.
37.3	1.6	The highway starts a gradual turn to the south. Now traveling on State Highway 15.
40.4	3.1	Intersection with Roberts County Road 18. Turn right (west). As we drive across the Big Stone moraine, the Coteau des Prairies is visible to the west.
43.4	3.0	Turn left (south) on gravel road.
43.6	0.2	Leave Big Stone moraine and reenter the valley of the North Fork of the Whetstone River.
44.2	0.6	Cross the river.
44.3	0.1	**STOP 3: FACETED BOULDER PAVEMENT**. Exposure of the New Ulm and Granite Falls tills and the sub-New Ulm boulder pavement. Refer to stop description on page 38.
		Continue south on gravel road.
44.4	0.1	Turn left (east) at intersection. As the road drops back into the river valley, pavement stones can be seen on the hillsides.
44.8	0.4	Cross river; 5 to 15 feet of stratified sediments fill the river valley in this area.
45.1	0.3	Leave river valley and move back onto the Big Stone moraine.
47.5	2.4	Intersection with State Highway 15. Turn right (south).
48.5	1.0	Leave Roberts County, enter Grant County.

49.0	0.5	Leave Big Stone moraine and reenter the valley of the North Fork of the Whetstone River.
49.9	0.9	Cross river and climb out of valley. The boulder pavement is exposed in the ditch and hillside on the east side of the road.
50.3	0.4	Pavement stones visible on the left (east).
51.0	0.7	**STOP 4: GRANITE FALLS TILL**. Exposure of Granite Falls till in stream valley. Refer to stop description on page 39.
		Continue south on State Highway 15.
51.5	0.5	Intersection with Grant County Road 4. Turn left (east).
53.3	1.8	Descend into the valley of the North Fork of the Whetstone River.
53.4	0.1	Cross river.
54.6	1.2	Leave valley. At this point the Big Stone moraine trends off to the northeast and we will be crossing ground moraine and thin outwash deposits.
55.5	0.9	Big Stone moraine is visible to the north.
56.7	1.2	Crossing small north-south trending ridge. This is an erosional remnant of New Ulm till.
57.5	0.8	Enter valley of the Whetstone River.
57.7	0.2	Cross river.
57.8	0.1	Turn left into the Carl Loraff farm. Park in yard. **STOP 5: LORAFF SECTION**. We will observe a cutbank exposure of the Hawk Creek till and the "gastropod silts" along the Whetstone River about a quarter mile northwest of the farm. Refer to stop description on page 40.
		Return to highway.
58.0	0.2	Turn left (east) onto Grant County Road 4. We will be driving across the highest (1,050 ft) terrace of the Whetstone River. At Ortonville it merges with terraces associated with the Herman stage of Lake Agassiz.
58.7	0.7	Turn left at road junction (Grant County Road 39). Follow road down off the terrace to the modern floodplain.

59.5	0.8	**STOP 6: GAGING STATION SECTION**. We will examine a cutbank exposure of the Hawk Creek and Whetstone tills exposed along the Whetstone River. Refer to stop description on page 42. Retrace route to intersection with Grant County Road 4.
60.4	0.9	Intersection with Grant County Road 4. Continue south on County Road 39.
60.7	0.3	Intersection with U.S. Highway 12. Turn left (east), again traveling on the high Whetstone terrace.
61.4	0.7	Descend into Whetstone River valley.
61.6	0.2	Hawk Creek till exposed in small cut near private driveway on the right (south).
61.7	0.1	Cross Whetstone River.
62.1	0.4	Leave river valley. Enter Big Stone City.
62.5	0.4	Intersection with Cornell Street. Turn left (north).
63.2	0.7	Big Stone City Park. **LUNCH BREAK**. Retrace route to Highway 12.
63.9	0.7	Turn left (east) onto U.S. Highway 12.
64.0	0.1	Enter Big Stone Lake/Minnesota River valley.
64.2	0.2	Cross U.S. Corps of Engineers diversion channel that routes the Whetstone River into Big Stone Lake to maintain a normal reservoir pool elevation of 966 feet. The lake surface is the lowest elevation in South Dakota.
64.3	0.1	Intersection with Grant County Road 47. Turn right (south). Cross the upper portion of the alluvial fan deposited by the Whetstone River in the abandoned valley of Glacial River Warren.
64.6	0.3	Cross the pre-diversion Whetstone River channel.
65.0	0.4	Travel across the Herman stage river terrace.
65.2	0.2	Bear left (southeast) at fork in the road into the state of Minnesota. Now traveling on Big Stone County Road 15.

65.6	0.3	Armored terrace remnant on the left (east). Granite quarries in the Minnesota River valley are also visible to the east.
66.0	0.4	Leave Big Stone County, enter Lac Qui Parle County. Now traveling on Lac Qui Parle County Road 6.
66.3	0.3	Granite bosses visible to the east.
67.3	1.0	Leave Herman stage terrace and move back onto late Woodfordian ground moraine.
69.9	2.6	Intersection with Lac Qui Parle County Road 40. Continue south on County Road 6.
70.9	1.0	Turn right (west) on gravel road.
71.9	1.0	Turn left (south) on gravel road.
72.6	0.7	Enter valley of the North Fork of the Yellow Bank River.
73.0	0.4	Cross river and park. **<u>STOP 7: NORDICK FARM SECTION</u>**. All of the major Quaternary stratigraphic units are exposed in a drainage ditch about 100 yards to the south. Refer to stop description on page 43.
		Continue west on gravel road.
73.4	0.4	The upper segment of the drainage ditch can be seen on the left (north).
74.3	0.9	Turn right (west) on gravel road.
75.1	0.8	Cross a portion of the Nordick drainage ditch and reenter South Dakota.
75.3	0.2	Turn left (south) at intersection.
77.5	2.2	Turn right (west) on gravel road.
78.1	0.6	**<u>STOP 8: BIG TOM HILL GRAVEL PIT</u>**. We will examine a gravel pit in one of a series of high, linear ridges found in the area. Refer to stop description on page 45.
		Continue west on gravel road.
78.5	0.4	Intersection with Grant County Road 39. Turn right (north).
81.5	3.0	Turn left (west) on gravel road.

82.1	0.6	Valley of the North Fork of the Yellow Bank River. Note faceted boulders exposed on the hillside to the left (south).
83.5	1.4	Turn right (north) on gravel road.
83.7	0.2	Turn right (east) into quarry. **STOP 9: DAKOTA ROSE GRANITE QUARRY**. We will examine glacially-abraded knobs of the Milbank granite, as well as evidence of Cretaceous weathering preserved in the lee of the knobs. Refer to stop description on page 47.
		Return to gravel road
83.9	0.2	Turn right (north) on gravel road.
84.6	0.7	Turn left (west) at intersection.
84.7	0.1	Turn right (north) onto paved road (Grant County Road 49).
84.8	0.1	Pass the Hunter quarry, the original granite quarry in the area, opened in 1908. An eroded granite knob can be seen on the right (east).
85.7	0.9	Intersection with Grant County Road 10 (former U.S. Highway 12). Turn left (west).
90.2	4.5	Milbank city limits.
90.7	0.5	Intersection with U.S. Highway 12. Turn left (southwest) into town.
91.8	1.1	Intersection with State Highway 15. Turn left (south).
99.6	7.8	Intersection with State Highway 20. Turn right (west), heading toward the Coteau des Prairies.
100.8	1.2	Cross one of many minor moraine ridges.
103.7	2.9	Gravel pits visible to the right (north) are located in fan-like outwash deposits commonly found at the base of the Coteau.
103.9	0.2	Begin steep ascent of the Coteau des Prairies.
104.3	0.4	The sub-New Ulm boulder pavement is exposed in the walls of the valley on the right (north) and in the ditch on the left (south).
105.5	1.2	Noticeable break in slope (Gary moraine).
107.6	2.1	Town of Stockholm on the left (south).

110.7	3.1	Proximal edge of the Altamont moraine.
111.7	1.0	Leave Grant County, enter Codington County.
112.0	1.3	Crest of the Altamont moraine.
112.7	0.7	Punished Womans Mound, the large, irregular hill visible to the south-southeast, is the highest point on the Bemis moraine.
112.9	0.2	Enter Antelope Valley. Meltwaters issuing from the Altamont moraine were ponded in this valley and escaped only through a few channels that cut through the Bemis/Toronto highland to the west. Over 80 feet of outwash is found in some areas of the valley, and these deposits serve as a major water source for northeastern South Dakota.
113.6	0.7	Town of South Shore.
114.8	1.2	Punished Womans Lake, visible to the right (north) is located at the head of one of the channels that drain Antelope Valley. From here the channel runs south, and then southwest, where it is occupied by Mud Creek, a tributary of the Big Sioux River. A low divide in the upper part of the channel ponded water in this area during periods of low flow. Prominent benches visible to the north are composed of fine sands and silts deposited during these times.
115.5	0.7	Glaciolacustrine sediments visible in the road ditch on the left (south).
116.1	0.6	Move onto proximal slope of the Bemis moraine. Note concentration of boulders.
116.6	0.5	Distal edge of the Bemis moraine. Pass onto the Toronto till plain.
116.8	0.2	Intersection with Codington County Road 7. Turn right (north).
117.1	0.3	Cross back onto Bemis moraine. From here the moraine trends off to the northwest.
119.0	1.9	Another drainage channel that originates in the Antelope Valley.
119.8	0.8	Leave Codington County, enter Grant County. Now traveling on Grant County Road 5.
121.5	1.7	Altamont moraine visible to the north and east.

121.8	0.3	Intersection with Grant County Road 14. Turn left (west). From here we will be crossing thin, Bemis-age ground moraine that mantles but does not mask the underlying Toronto surface.
123.5	1.7	Distal edge of the Bemis moraine. Move onto the Toronto till plain.
125.3	1.8	Pass under Interstate 29.
125.6	0.3	At the jog in the road we cross back into the Lake Traverse Indian Reservation.
127.5	1.9	Intersection with Grant County Road 81. Turn right (north).
128.0	0.5	The James lobe Dakota moraine is visible at the western horizon.
128.6	0.6	Valley of the Indian River.
128.9	0.3	Note large Gasser deposits (C. Matsch, personal communication, 1986) on right (east).
130.6	1.7	Intersection with Grant County Road 8. Turn left (west). Continue across Toronto surface.
133.2	2.6	Enter valley of the Big Sioux River.
133.3	0.1	Cross river.
133.6	0.3	Move onto high river terrace.
133.8	0.2	Return to Toronto till plain.
136.5	2.7	Grant County and Day County line. Turn right (north). Dakota moraine looms ominously on the left (west).
136.8	0.3	<u>**STOP 10: THURMAN GRAVEL PIT**</u>. We will examine the interior of the Dakota moraine as exposed in a gravel pit southwest of the farm. Refer to stop description on page 49. Continue north on County line road.
137.8	1.0	Cross drainage channel that breaches the Dakota moraine.
141.6	3.8	Intersection is the common boundary of Grant, Day, and Roberts Counties. Turn right (east), following Grant County Road 24.
142.6	1.0	Turn left (north) and enter Roberts County. Now traveling on Roberts County Road 15.

143.6	1.0	Stay on Roberts County 15 as it turns to the right (east).
144.1	0.5	Stay on Roberts County 15 as it turns to the left (north).
145.1	1.0	Enter town of Ortley.
145.7	0.6	Intersection with U.S. Highway 12. Turn left (west) and head toward the Dakota moraine.
147.1	1.4	Leave Roberts County, enter Day County.
148.8	1.7	Cross the James lobe Dakota moraine.
149.7	0.9	Intersection with Enemy Swim Lake Road (Day County Road 1). Turn right (north) and follow road back to NeSoDak.
151.8	2.1	Doughnut on the left (west).
156.3	4.5	As road swings to the west, continue straight (north) on gravel road.
157.1	0.8	Return to NeSoDak. End of Day 1 field trip.

GEOLOGIC ROAD LOG - SUNDAY, MAY 14, 1989

by
Martin Jarrett, Jay Gilbertson, and Layne Schulz

0.0	0.0	Assemble in the NeSoDak parking lot. Proceed south on peninsula road, bearing right at substation, to junction with Enemy Swim Lake Road (Day County Road 1).
0.6	0.6	Continue south on Enemy Swim Lake Road. We will be crossing an area of late Woodfordian outwash, some of which is collapsed.
2.8	2.2	**STOP 11: SOIL GENESIS IN PRAIRIE POTHOLES**. We will examine some of the factors influencing soil development on the late Woodfordian landscape. Refer to stop description on page 50.
		Continue south on Day County Road 1.
3.1	0.3	Cross drainage channel that once connected Enemy Swim Lake to the north and Blue Dog Lake to the south.
6.2	3.1	Blue Dog Lake on the right (west).
7.3	1.1	Intersection with U.S. Highway 12. Turn right (west) and drive along the southern edge of Blue Dog Lake.
8.7	1.4	Turn left (south) into the town of Waubay.
9.5	0.8	Cross railroad tracks.
9.7	0.2	Intersection with Jones Avenue. Turn left (east).
10.2	0.5	Intersection with Day County Road 1. Turn right (south).
11.7	1.5	Bitter Lake is visible to the right (west). It is the last of a series of lakes in a closed drainage basin. As the name implies, the water quality is not very good. Our next stop today will be at a similar lake in Codington County.
12.6	0.9	Crest of the James lobe Dakota moraine. For the next 2 miles we will be traversing the distal slope of the moraine, before crossing back behind it.
15.0	2.4	Another view of Bitter Lake with its fringing salt flats.

16.0	1.0	Move off the Dakota moraine and into an area of low- to moderate-relief stagnation moraine. This is typical topography for the Coteau des Prairies west of the Dakota moraine.
23.2	7.2	Leave Day County, enter Codington County. Now traveling on Codington County Road 19.
28.2	5.0	Good view of the Dakota moraine to the left (east).
30.0	1.8	Enter a channel that breaches the Dakota moraine.
32.4	2.4	Leaving distal portion of the Dakota moraine. The high ridge visible to the left (east) is probably the western limit of the Toronto till plain (Still Lake moraine).
33.2	0.8	Climb onto a segment of the Brookings till plain.
34.1	0.9	Leave Brookings surface and move onto late Woodfordian collapsed outwash.
34.3	0.2	Intersection with State Highway 20 and Codington County Road 6A. Cross State Highway 20 and turn right (west) on Codington 6A.
35.7	1.4	Gravel pit on the right (north) developed in collapsed outwash. A complex sequence of collapsed terraces is visible on the left (south).
36.9	1.2	Several closed-basin lakes are visible on the left (south).
37.3	0.4	Junction with Codington County Road 23. Continue west.
38.7	1.4	Road starts a gradual swing to the south.
39.5	0.8	Bear left (south-southeast) on gravel road.
40.1	0.6	**<u>STOP 12: MEDICINE LAKE</u>**. We will discuss the origin of saline lakes in the region and the physical and vegetational history of the lake. Refer to stop description on page 51. When leaving the stop, drive straight west.
40.6	0.5	Intersection with Codington County Road 23. Turn left (southwest).
44.7	4.1	Intersection with Codington County Road 10. Turn left (east).

47.0	2.3	Crossing old lake bed.
49.2	2.2	City of Watertown visible to the east.
50.7	1.5	Intersection with South Lake Drive (State Highway 139). Turn right (south), following the western shore of Lake Kampeska.
52.6	1.9	Intersection with Codington County Road 14. Turn left (east) toward the Sandy Shore State Recreation Area.
53.0	0.4	**STOP 13: SANDY SHORE STATE RECREATION AREA**. This will be a short stop for refreshments before we start the big push south. Retrace route to South Lake Drive.
53.4	0.4	Intersection with South Lake Drive. Turn left (south).
53.6	0.2	Intersection with U.S. Highway 212. Turn left (east).
54.5	0.9	Climbing proximal slope of the Dakota moraine.
55.0	0.5	Crest of the Dakota moraine and then descend distal outwash apron.
55.6	0.6	Move onto segment of the Toronto till plain.
56.2	0.6	For the next several miles we will be crossing late Woodfordian outwash deposits. The rounded hills that rise above the outwash are portions of the Toronto till plain (early Woodfordian).
58.6	2.4	Watertown city limits.
59.4	0.6	Intersection with State Highway 20. Continue straight (east).
59.8	0.4	Cross the Big Sioux River. The channelized segment on the right (south) contains a diversion structure that is used to maintain the water level of Pelican Lake to the southwest.
60.5	0.7	Intersection with U.S. Highway 81. Turn right (south) and continue across the outwash.
61.2	0.7	Cross Big Sioux River.
61.9	0.7	Move onto Toronto till plain.
66.5	4.6	Leave Codington County, enter Hamlin County.

67.2	0.7	The Dakota moraine is visible to the right (southwest).
72.7	5.5	Cross meltwater channel heading at the Dakota moraine.
73.8	1.1	Another meltwater channel.
74.0	0.2	U.S. Highway 81 bends to the southwest and climbs the distal slope of the Dakota moraine.
74.9	0.9	Crest of the moraine.
75.5	0.6	Move back onto stagnation moraine of the late Woodfordian James lobe.
76.9	1.4	Junction with State Highway 21. Continue south, crossing part of an old lake basin.
77.9	1.0	Move back onto stagnation moraine.
80.7	2.8	Junction with State Highway 28. Continue south, crossing part of another lake basin.
81.5	0.8	Move back onto stagnation moraine.
83.4	1.9	Lake plain associated with Lake Poinsett.
83.9	0.5	Lake Poinsett, the largest natural lake in South Dakota, is on the left (east).
85.0	1.1	Leave Hamlin County, continue south on U.S. 81 following the Kingsbury County (right/west) and Brookings County (left/east) line.
85.3	0.3	Lake Albert is on the right (west).
85.9	0.6	Part of Lake Albert lake plain.
86.6	0.7	Move back onto stagnation moraine.
96.0	9.4	Turn left (east) into Brookings County onto County Road 8. Continue across stagnation moraine.
98.0	2.0	Good view of the Big Sioux River valley to the east.
99.3	1.3	**STOP 14: ICE-WALLED LAKE PLAIN**. We will examine a rather large ice-walled lake plain and a number of smaller collapse features in the area. Refer to stop description on page 53. Continue east on Brookings County Road 8.

99.9	0.6	Climb onto the ice-walled lake plain.
102.2	2.3	Leave the ice-walled lake plain. Move onto the Dakota moraine. Notice the difference between the moraine here in Brookings County and that observed farther north.
105.5	3.3	Looking to the northeast, you can see the low-relief surface of the Brookings till plain.
106.0	0.5	Intersection with Brookings County Road 5. Continue east.
106.3	0.3	Outwash of the Big Sioux valley train.
106.8	0.5	Cross the Big Sioux River.
108.0	1.2	Intersection with Brookings County Road 7. Continue east.
109.1	1.1	Cross North Deer Creek.
109.7	0.6	**STOP 15: BROOKINGS TILL PLAIN**. Turn right (south) into the parking lot of the old Sterling Church. We will examine the evidence for the Brookings till plain. Refer to stop description on page 54.

This is the last stop and hence the end of the trip. Following are some general directions for getting back to the "real" world.

To go **WEST**: Retrace our route on Brookings County 8 to U.S. Highway 81. Turn left (south) toward the town of Arlington. From there you can take U.S. Highway 14 to Huron and points west.

To go **NORTH**: Continue straight (east) on Brookings County 8 for 3.3 miles to the intersection with Brookings County Road 77. Turn left (north) and follow road to intersection with State Highway 30 (3.0 miles). Turn right (east) and proceed to Interstate 29.

To go **SOUTH** and **EAST**: Continue straight (east) on Brookings County 8 for 3.3 miles to the intersection with Brookings County Road 77. Turn right (south) and follow road into the city of Brookings (about 4 miles). From here you can go east on U.S. Highway 14 or south on Interstate 29.

Happy trails!!

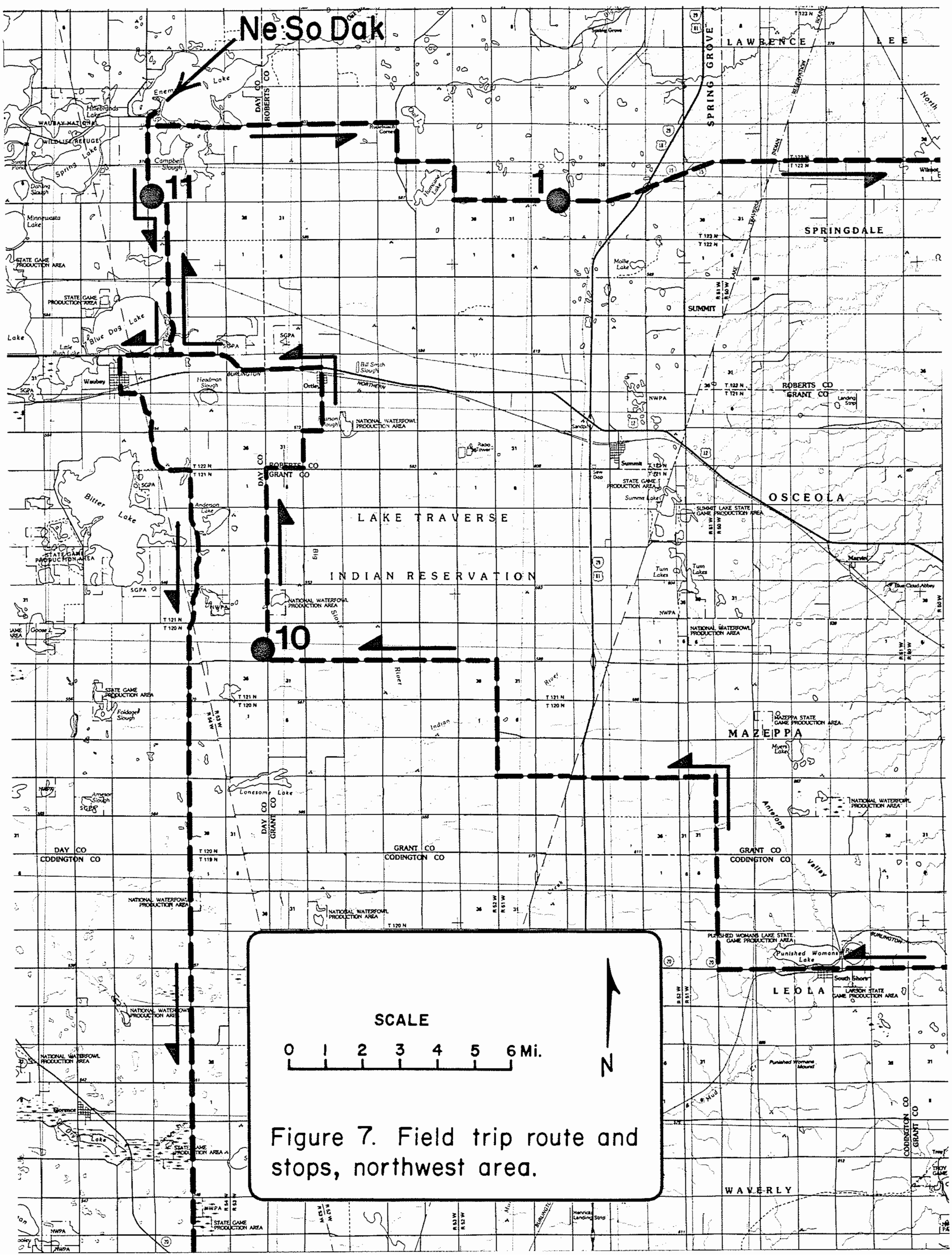


Figure 7. Field trip route and stops, northwest area.

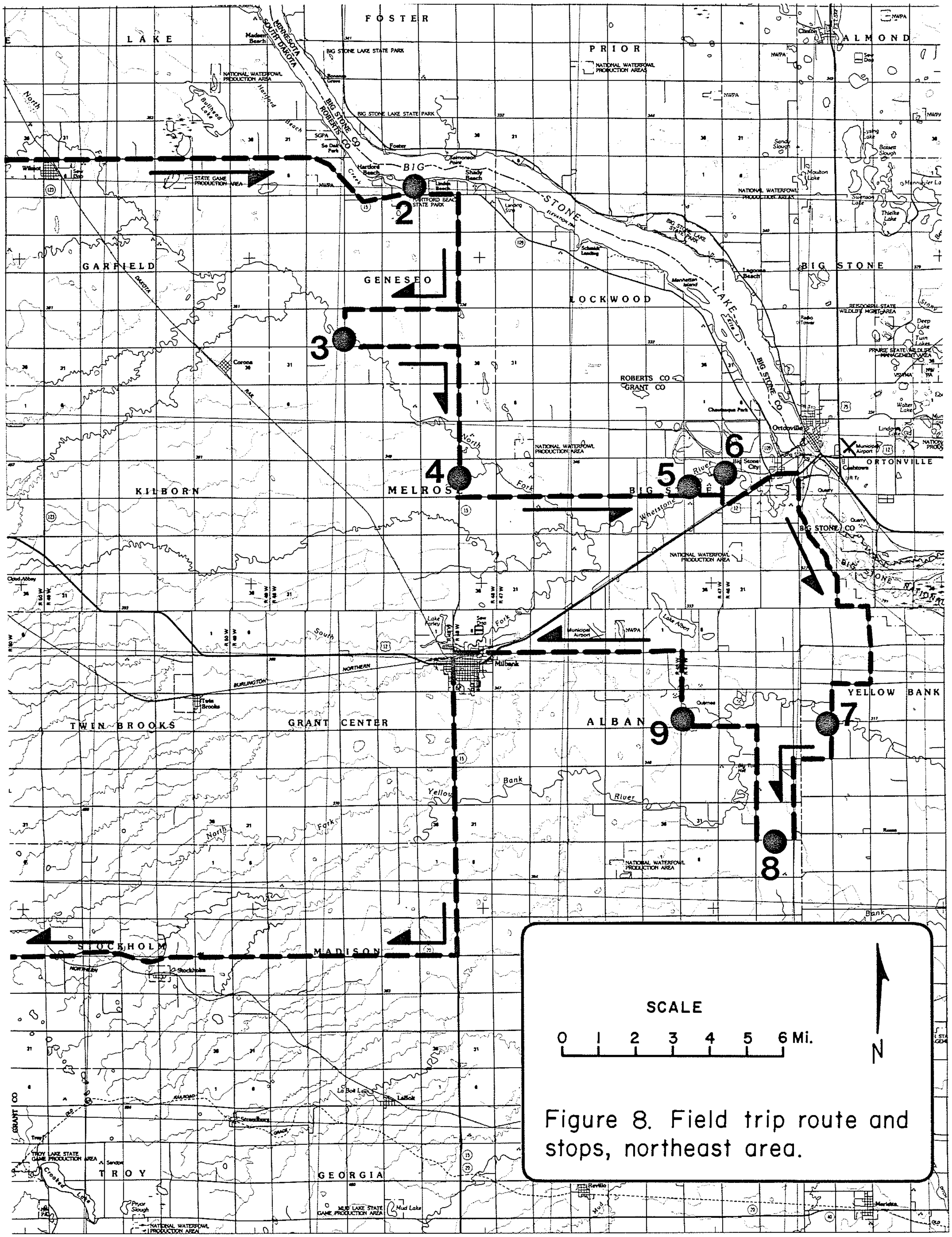


Figure 8. Field trip route and stops, northeast area.

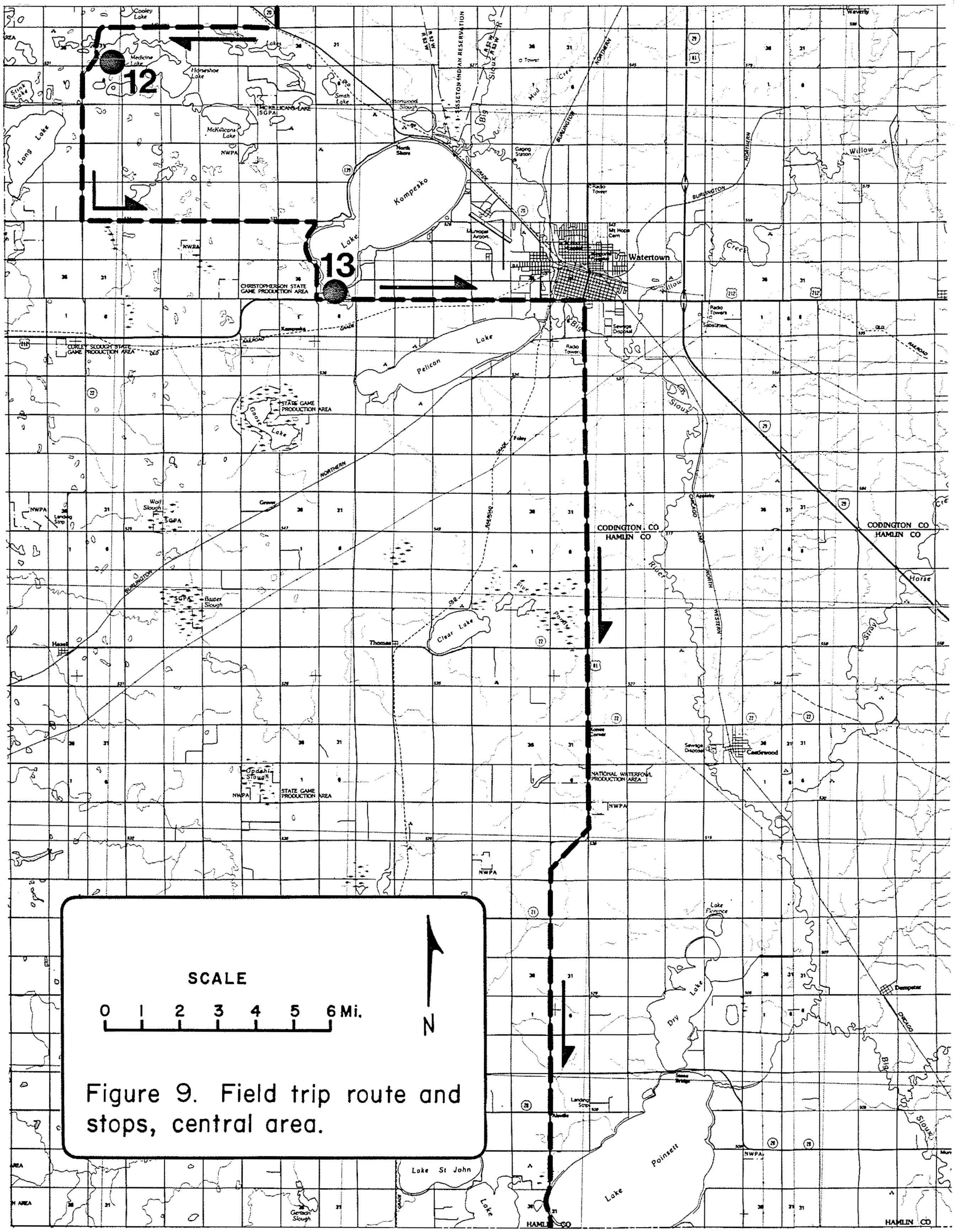


Figure 9. Field trip route and stops, central area.

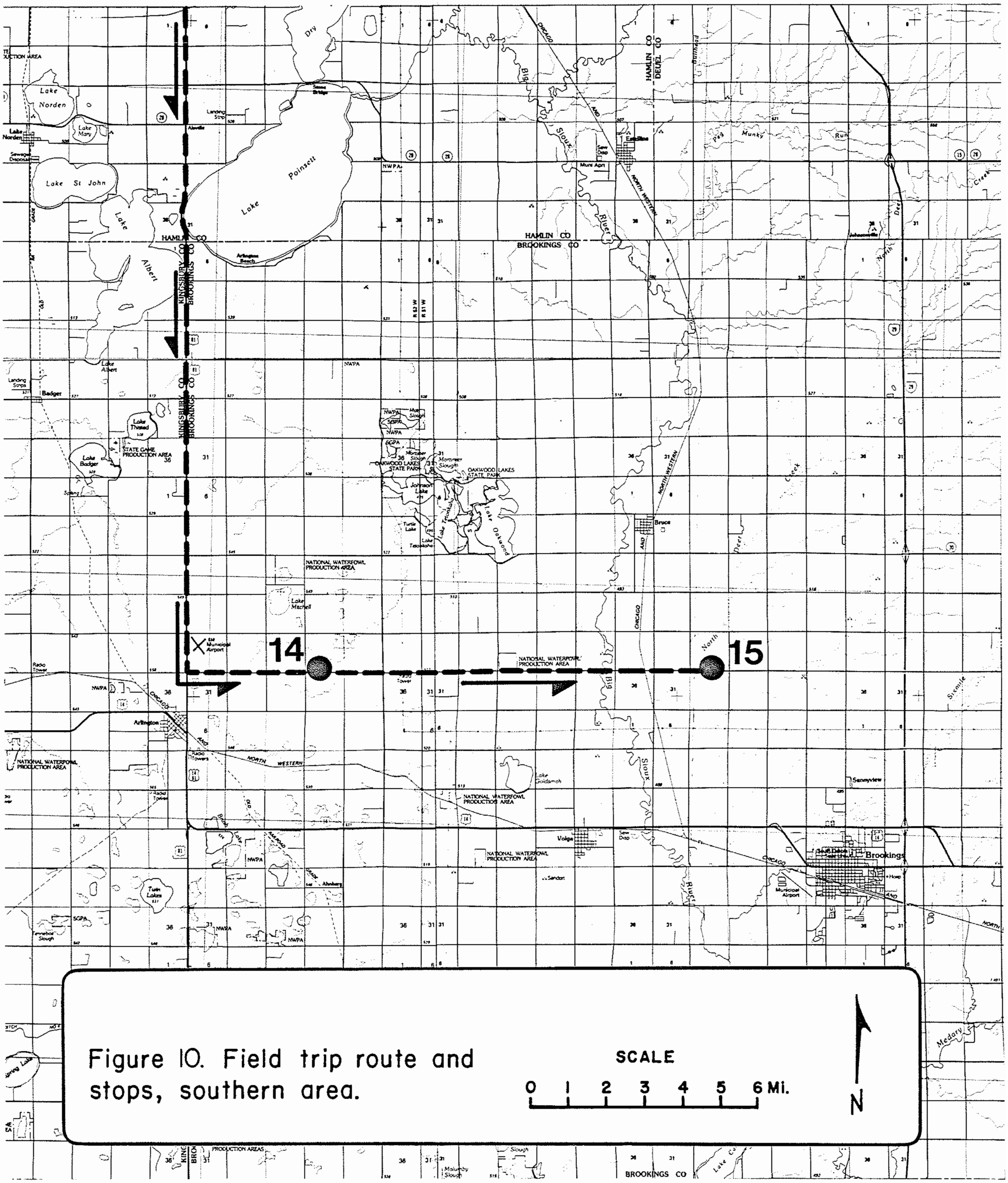


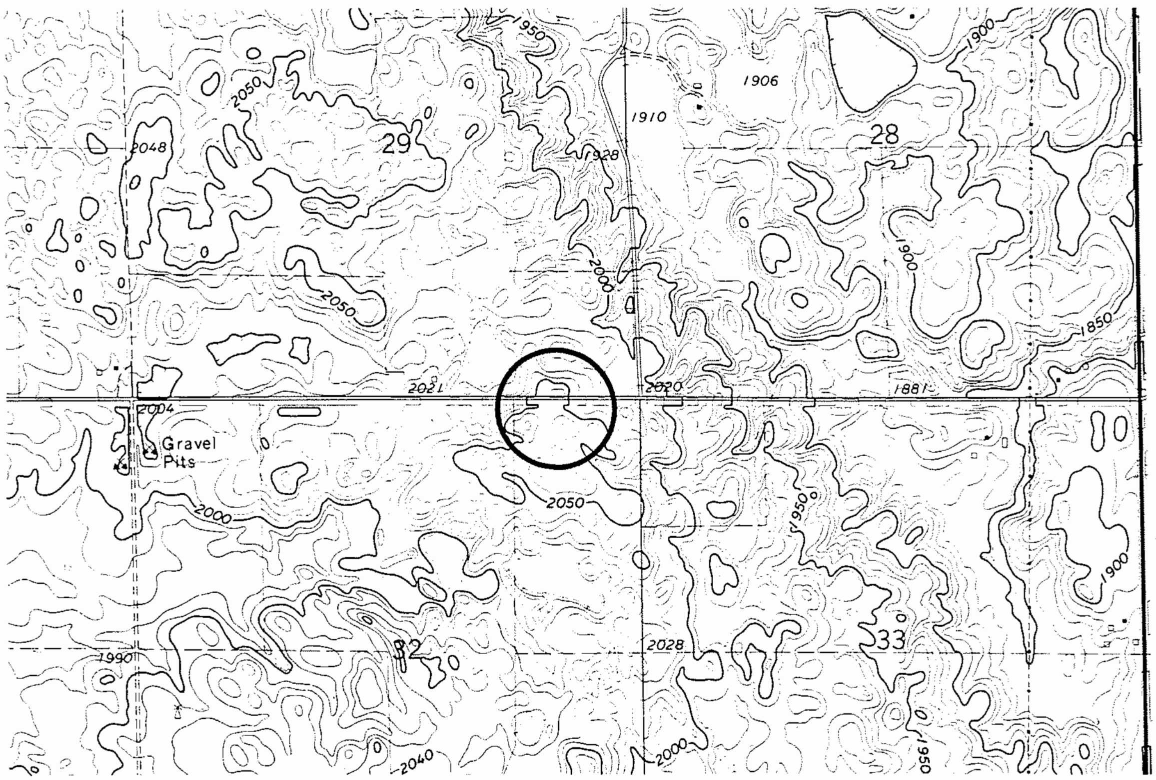
Figure 10. Field trip route and stops, southern area.

GEOLOGIC STOP DESCRIPTIONS

By
Jay Gilbertson and Martin Jarrett

STOP 1

Title: Edge of the Coteau des Prairies



Location: NW$\frac{1}{4}$NE$\frac{1}{4}$NE$\frac{1}{4}$ sec. 32, T. 123 N., R. 51 W., Reservation, Roberts County, South Dakota; Summit NE $7\frac{1}{2}$-minute topographic quadrangle. C.I. = 10'. Radio relay tower on south side of Roberts County Road 17.

We will make a brief stop here to observe the margin of the Coteau des Prairies and partake of the spectacular views of the surrounding country. Jean N. Nicollet, working for the Bureau of the Corps of Topographical Engineers, visited the Coteau in the late 1830's. His description of the area at that time differs little from what we can observe today.

> " *The plain at its northern extremity is a most beautiful tract of land, diversified by hills, dales, woodlands and lakes, the last abounding with fish. This region of country is probably the most elevated between*

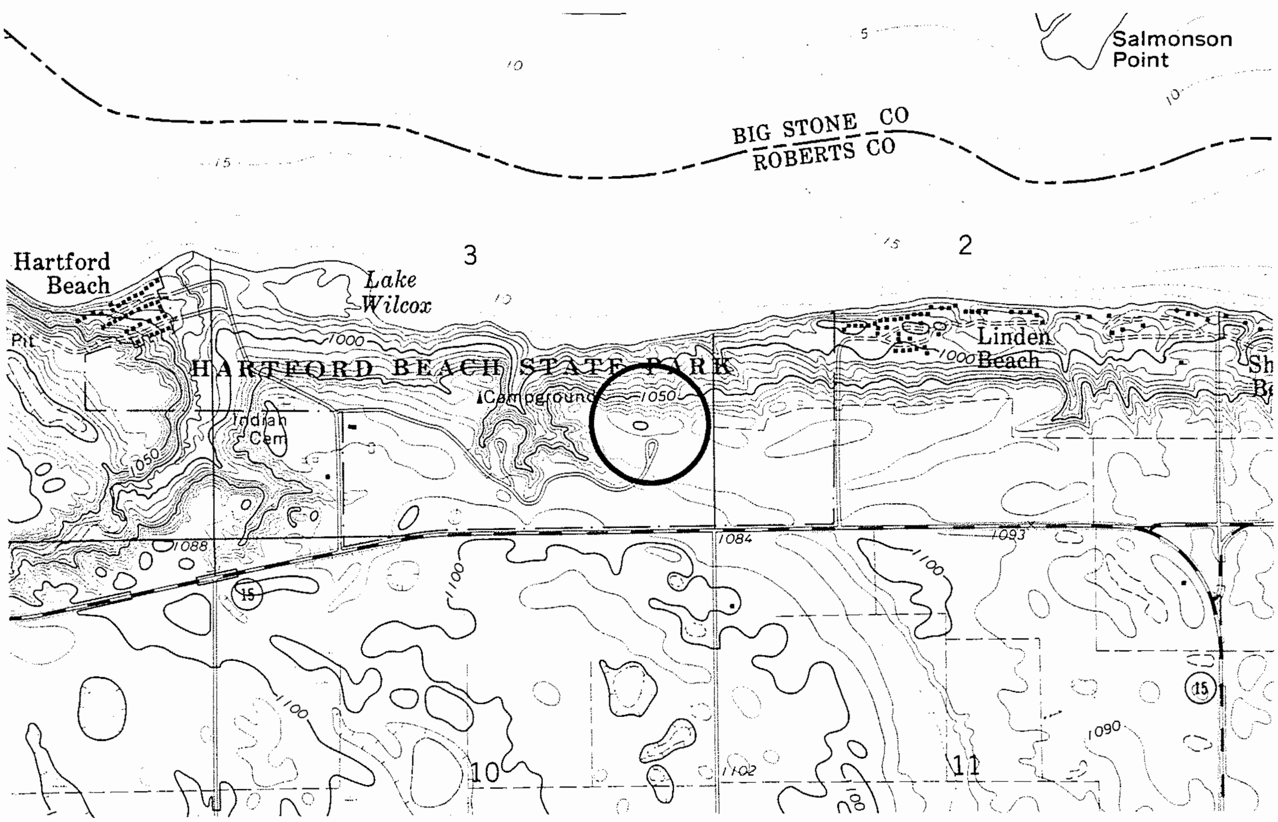
the gulf of Mexico and Hudson's bay. From its summit, proceeding from its western to its eastern limits, grand views are afforded. At its eastern border, particularly, the prospect is magnificent beyond description, extending over the immense green turf that forms the basin of the Red river of the North, the forest-capped summits of the hauteurs des terres that surround the sources of the Mississippi, the granitic valley of the upper St. Peter's (Minnesota River), and the depressions in which are lake Traverse and Big Stone lake. There can be no doubt that in future times this region will be summer resort of the wealthy of the land." (Winchell and Upham, 1884).

This stop is located on one of the higher segments of the Altamont moraine, although at the northern end of the Coteau des Prairies it is often difficult to separate the various moraines of the late Woodfordian Des Moines Lobe. The moraine is composed primarily of collapsed glaciofluvial sediments. Numerous linear ridges with adjacent valleys suggest that glaciotectonic stacking has been involved in building the moraine, although test holes drilled along the moraine have not found evidence of repetitive units.

This ridge is the drainage divide between the Minnesota and Mississippi drainage to the east and the Big Sioux and Missouri basin to the west.

STOP 2

Title: Big Stone Lake and Glacial River Warren



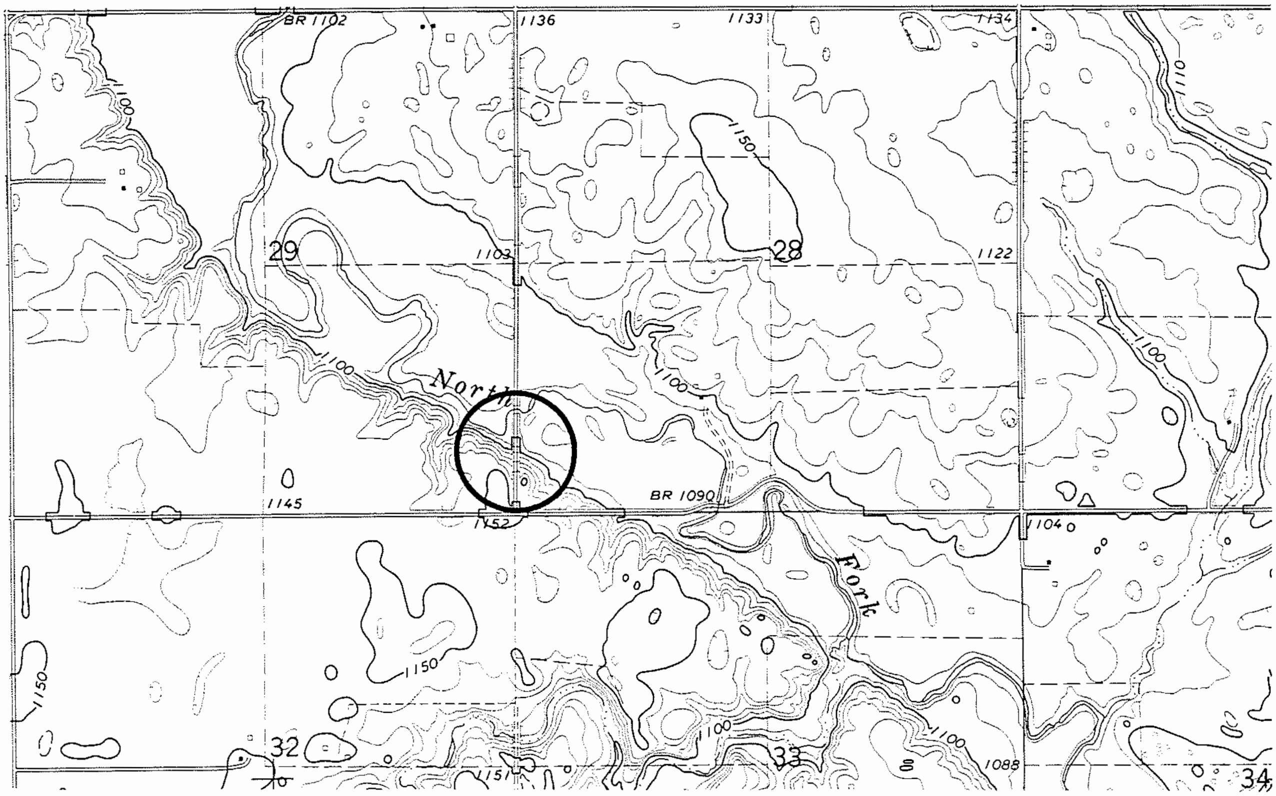
Location: NW¼SE¼SE¼ sec. 03, T. 122 N., R. 48 W., Roberts County, South Dakota; Big Stone Lake West, Minnesota-South Dakota 7½-minute topographic quadrangle. C.I. = 10'. Scenic overlook on the south side of Big Stone Lake in Hartford Beach State Park.

From the overlook one can see the valley of Glacial River Warren, which at times served as the southern outlet for Lake Agassiz. Initial establishment of the channel probably took place about 11,700 yr B.P. and it was active until about 11,000 yr B.P., during the Cass and Lockhart Phases of Lake Agassiz (Fenton and others, 1983). The channel was temporarily abandoned during the Moorhead Phase as a lower, eastern outlet sent meltwaters into the Lake Superior basin. The channel was last utilized during the Emerson Phase (approximately 9,900 to 9,500 yr B.P.), when the eastern outlets were blocked by the Marquette phase of the Superior lobe. Following abandonment of the channel, tributary streams deposited sediment fans that blocked portions of the valley, producing a series of long, shallow river lakes.

Big Stone Lake was formed when the Whetstone River built a sediment fan across the valley near Ortonville.

STOP 3

Title: Faceted boulder pavement

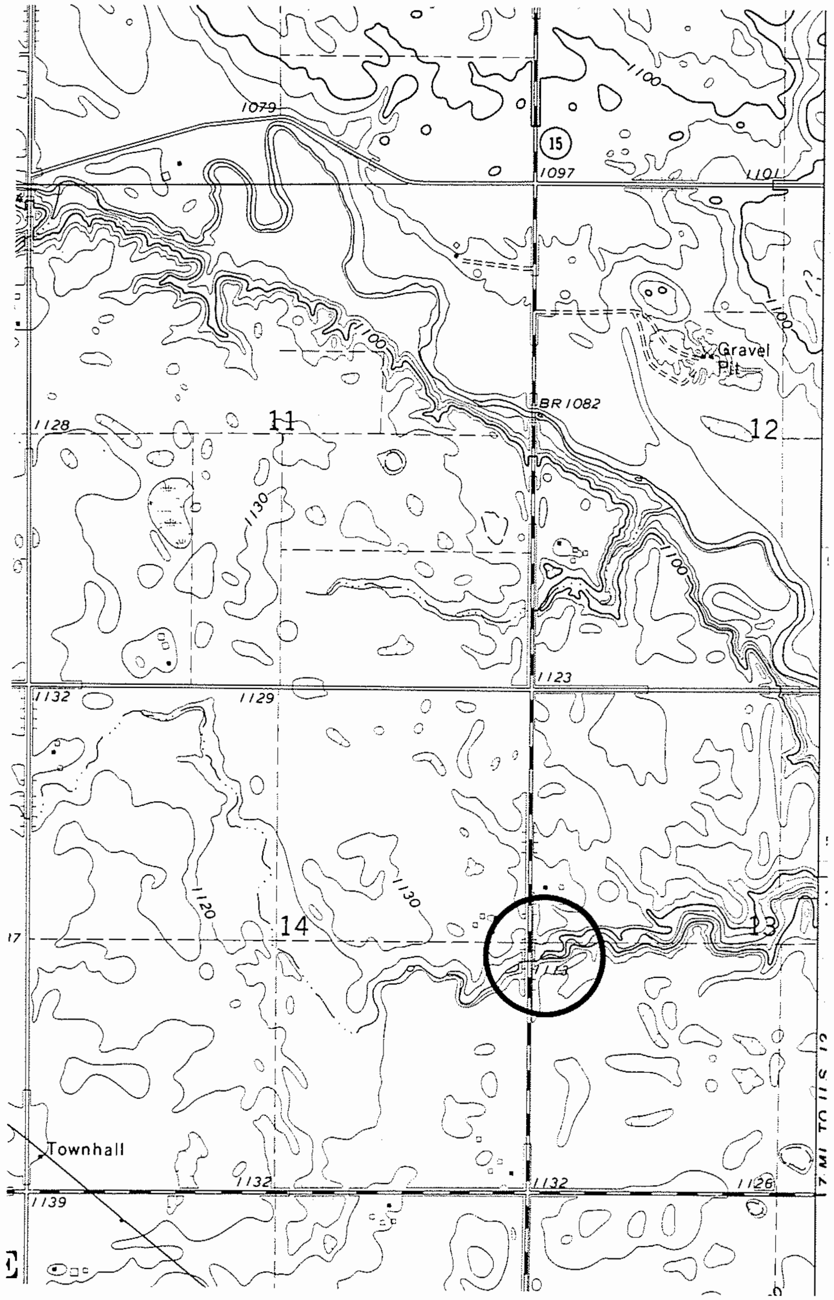


Location: SE¼SE¼SE¼ sec. 29, T. 122 N., R. 48 W., Roberts County, South Dakota; Big Stone Lake SW 7½-minute topographic quadrangle. C.I. = 10′. Road cut on west side of gravel road.

In the ditches on either side of the road can be found exposures of a single-layer, faceted boulder pavement. The pavement can be found throughout the area, and at all exposures marks the base of the shale-rich, late Woodfordian New Ulm till. At this site it separates the New Ulm till and the shale-poor Granite Falls till. At other sites it is found separating the New Ulm till from older units (Hawk Creek and Whetstone tills), as well as Cretaceous bedrock. Striations (S 42°E at this location) on the upper faceted surfaces of the stones are generally parallel to the long axis of the stones (Stahman & Cotter, 1985/86).

STOP 4

Title: Granite Falls till

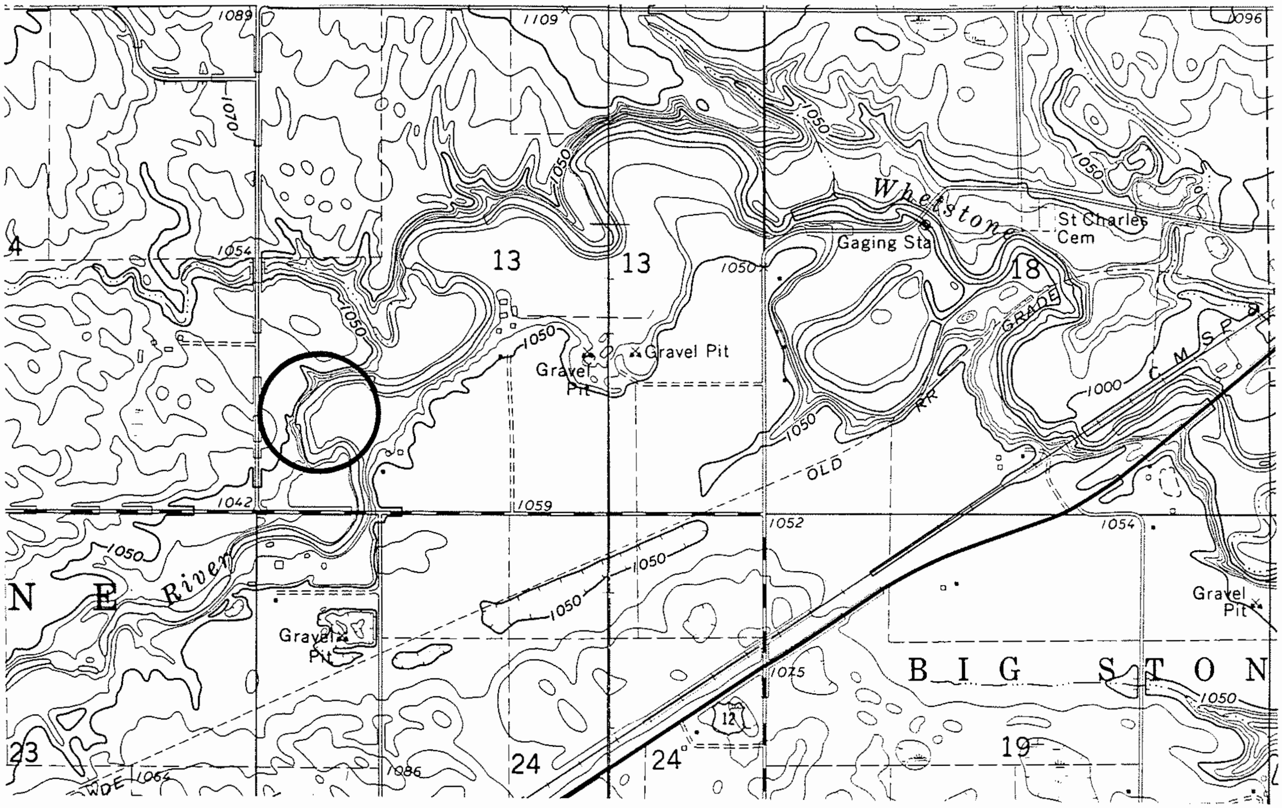


Location: NW¼NW¼SW¼ sec. 13, T. 121 N., R. 48 W., Grant County, South Dakota; Big Stone Lake SW 7½-minute topographic quadrangle. C.I. = 10′. Cutbank exposure in small stream just east of South Dakota Highway 15.

Exposed in the ditch at this site is the Granite Falls till, along with remnants of the regional boulder pavement. This site is unique in that it is one of the few surface exposures of unoxidized Granite Falls till.

STOP 5

Title: Loraff Farm Section



Location: NW¼SW¼SW¼ sec. 13, T. 121 N., R. 47 W., Grant County, South Dakota; Big Stone Lake SE, South Dakota-Minnesota 7½-minute topographic quadrangle. C.I. = 10'. Cutbank exposure along the west side of the Whetstone River, about 300 yards north of Grant County Road 4.

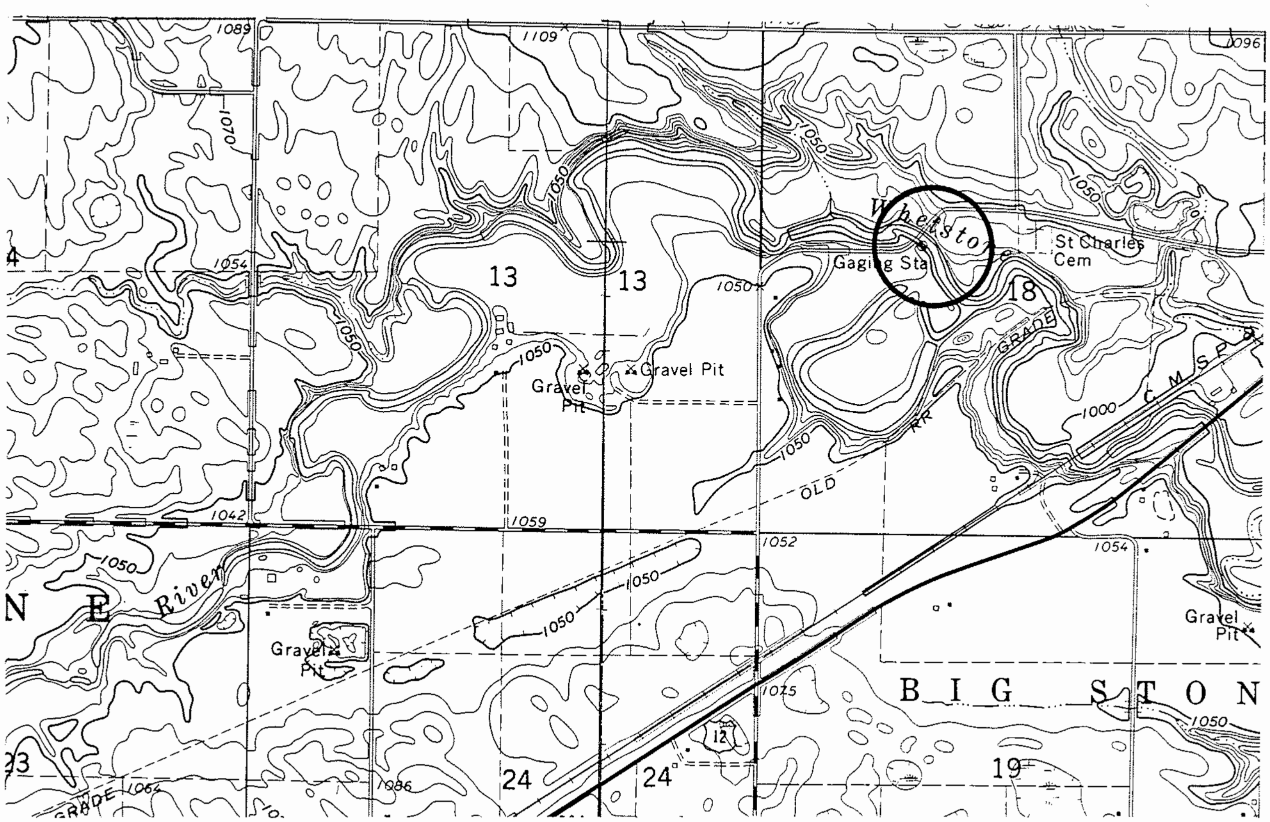
At this site, 34 feet of Hawk Creek till overlies the Gastropod silts.

The Gastropod silts are composed of two separate lithologies at this site. Most common is a massive, gray sandy silt containing numerous gastropod shells. Interbedded with the silts are coarse, iron-stained pebbly sands. The top of the unit is marked by a dark, grayish-brown organic-rich horizon.

The lower few feet of the overlying Hawk Creek till contains thin (0.25 to 1 inches) stringers of gray till(?), as well as bullet-clasts of a well-indurated gray till oriented parallel to the lower contact. Above this zone the till is fairly massive, with little sorted sediments present. A pronounced color change takes place approximately 14 feet above the base of the till, marking the transition from unweathered to weathered till. At the top of the section are several faceted boulders, part of the regional, sub-New Ulm till boulder pavement.

STOP 6

Title: Gaging Station Section



Location: SW$\frac{1}{4}$SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 18, T. 121 N., R. 46 W., Grant County, South Dakota; Ortonville, Minnesota-South Dakota 7$\frac{1}{2}$-minute topographic quadrangle. C.I. = 10′. Cutbank exposure along the east side of the Whetstone River, about 1 mile west of Big Stone City.

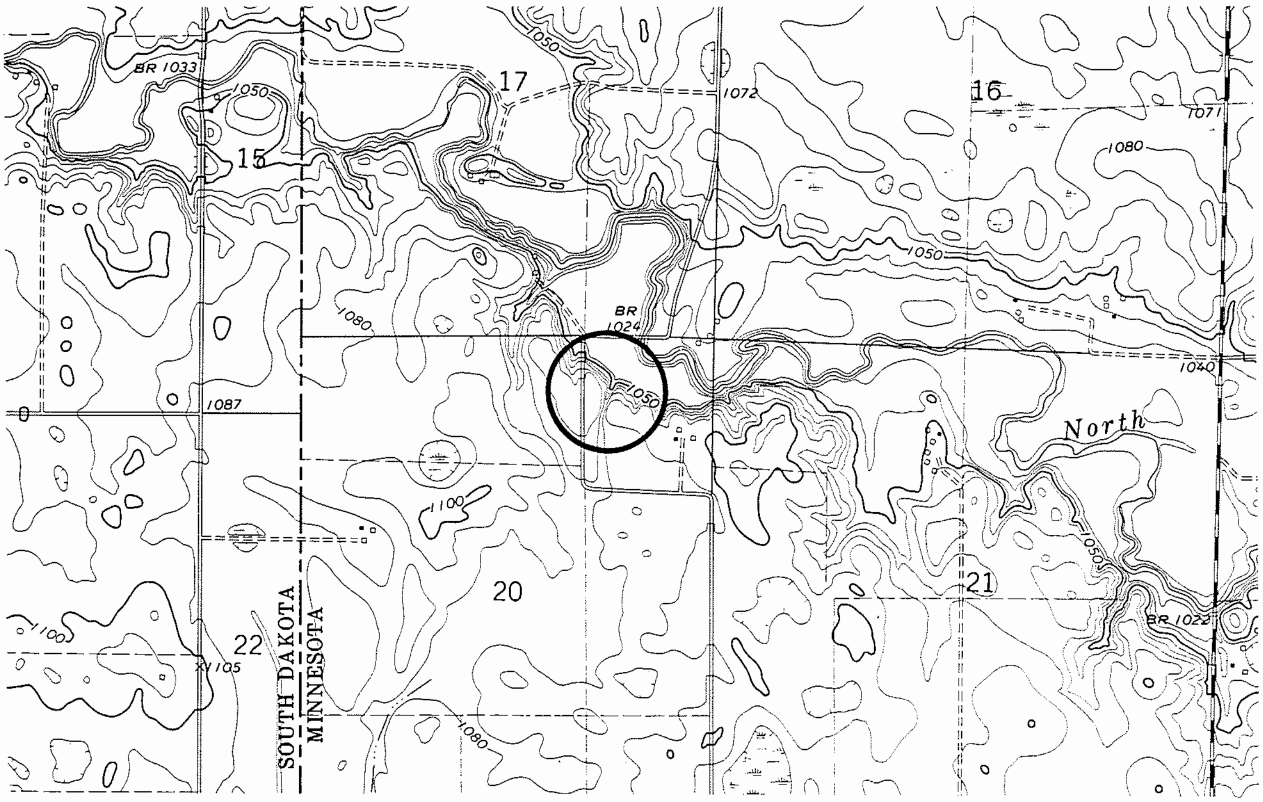
The section exposed in the bank across the Whetstone River has the three lowermost Quaternary units exposed in northeastern South Dakota. Unfortunately, we will not be able to examine the exposure up close.

Gaging Station section:	Colluvium	26 to 27 feet
	Hawk Creek till	12 to 26 feet
	Gastropod silts	4 to 12 feet
	Whetstone till	0 to 4 feet

Small seeps can be seen emanating from the base of the Gastropod silts unit at this site.

STOP 7

Title: Nordick Farm Section



Location: SW¼NE¼NE¼ sec. 20, T. 120 N., R. 46 W., Lac Qui Parle County, Minnesota; Rosen, Minnesota-South Dakota 7½-minute topographic quadrangle. C.I. = 10'. Exposure in a drainage ditch leading to the North Fork of the Yellow Bank River, about 1.2 miles west of Lac Parle County Road 6.

Originally constructed to alleviate drainage problems in some of the low, swampy ground to the south, this ditch now exposes approximately 60 feet of Quaternary deposits. It is one of the few places where all of the major drift units in the upper Minnesota River valley are exposed.

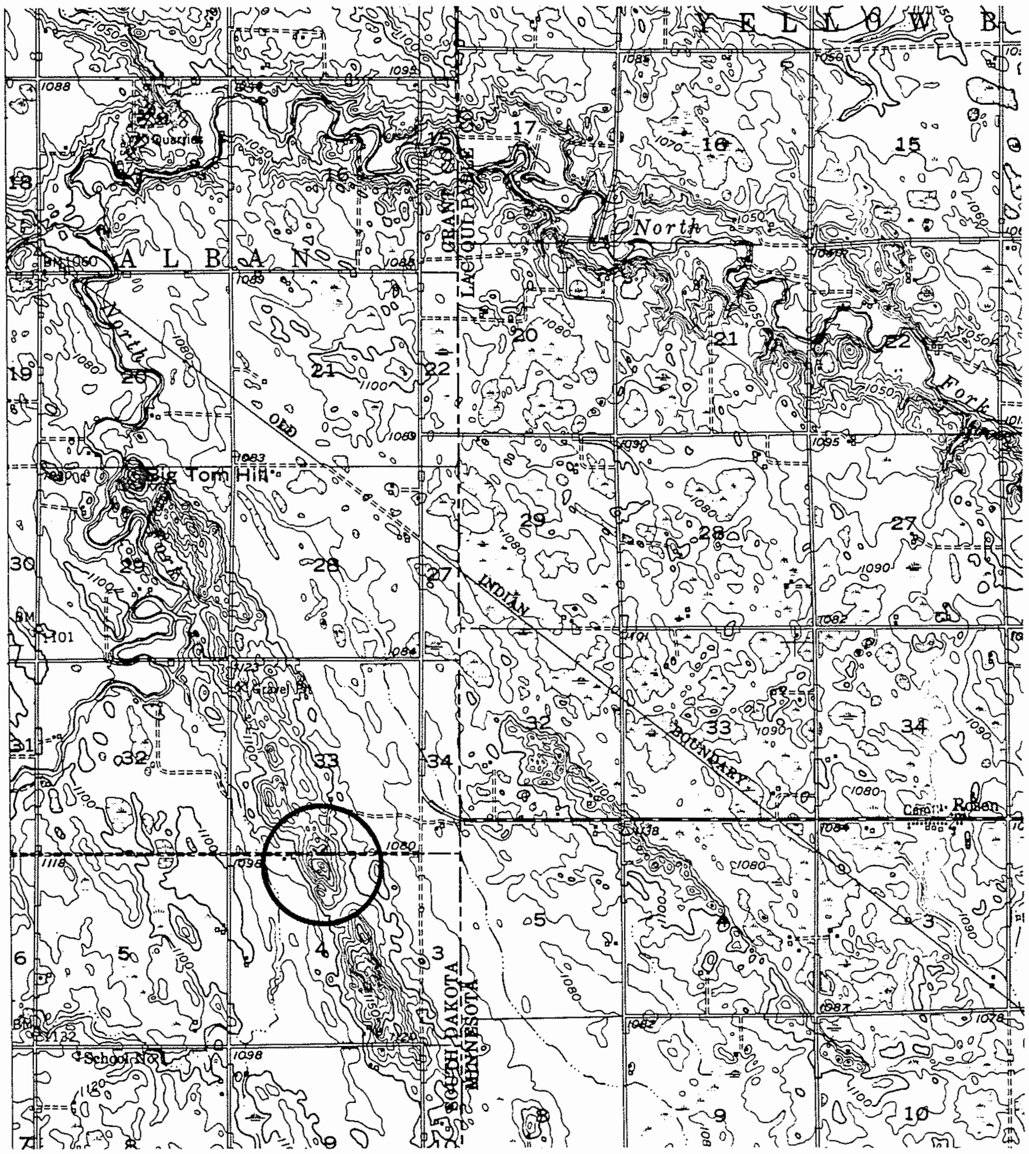
About 9 feet of massive, dark-gray Whetstone till is found along the lower portion of the ditch, although the total thickness at this site is unknown. Where it is not visible, the top of the Whetstone is marked by groundwater seeps, similar to those observed at Stop 6. The Whetstone till is overlain by 12 to 18 inches of Gastropod silts. Poorly exposed, the silts are mostly a structureless, dark grayish-brown sandy silt, with organic material and a few gastropod shells found throughout.

Approximately the next 12 feet of section is a combination of Granite Falls and Hawk Creek tills. Good exposures of the Hawk Creek till are found at the mouth of the ditch, where the Granite Falls is absent. The Granite Falls till is found mostly in the interior of the cut, in places lying directly on the Gastropod silts. Inclusions of Hawk Creek till, and occasionally the Gastropod silts, are found within the lower part of the Granite Falls till.

Faceted boulders litter the floor of the ditch, although no well-developed pavement is visible in the walls of the ditch. The base of the New Ulm till is marked by a 1- to 2-foot thick sequence of sand and fine gravels, with abundant shale clasts. From this level to the top of the ditch (about 38 feet), the New Ulm till contains numerous inclusions of sorted sediments, suggesting a supraglacial origin for at least part of this unit.

STOP 8

Title: Big Tom Hill



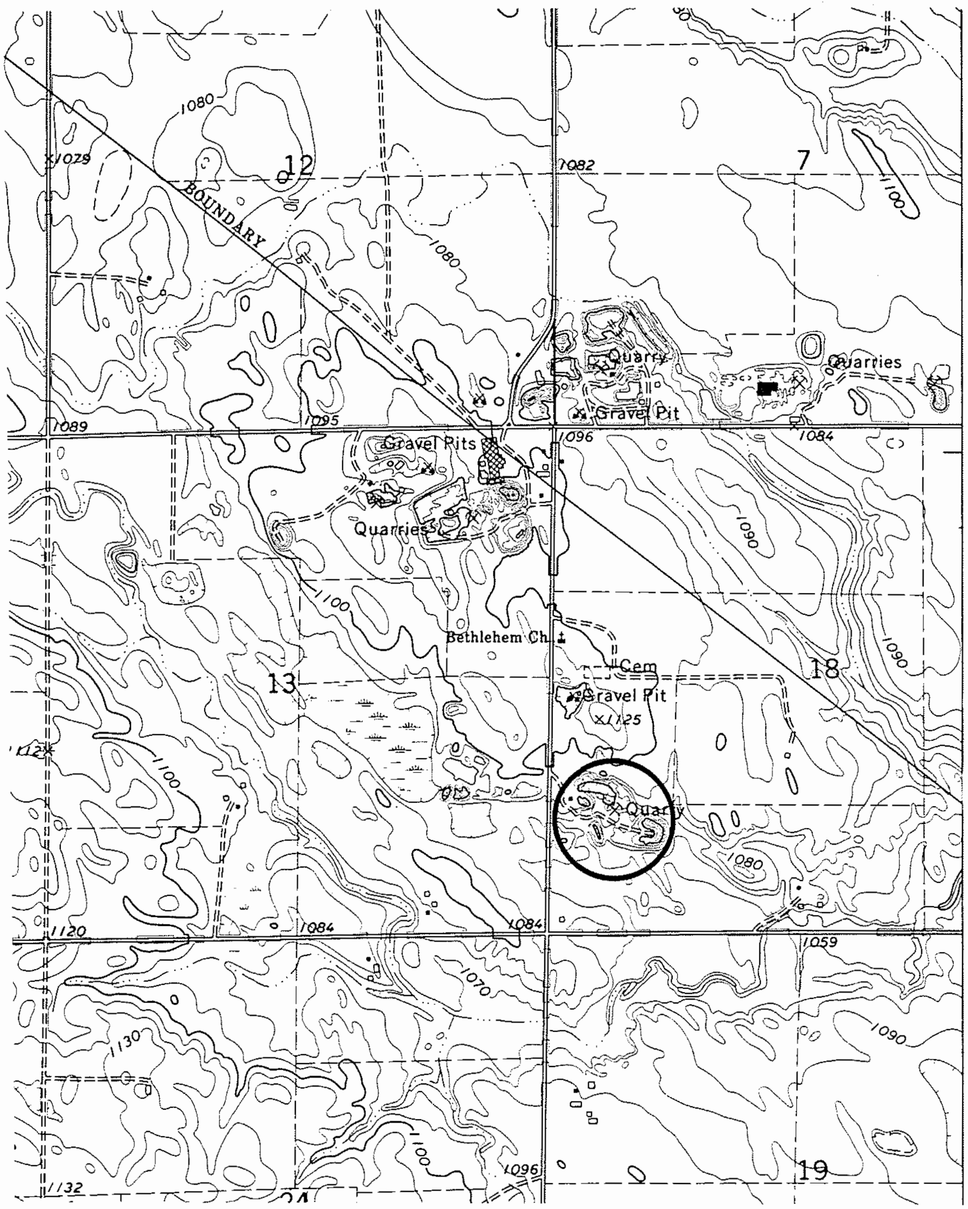
Location: NE¼NE¼NW¼ sec. 04, T. 119 N., R. 47 W., Grant County, South Dakota; Bellingham, Minnesota-South Dakota 15-minute topographic quadrangle. C.I. = 10'. East wall in gravel pit about ½ mile east of Grant County Road 39.

This stop is a gravel pit in a linear ridge locally known as Big Tom Hill. This ridge is the largest of a series of southeast trending, sub-parallel hills in the area. Rising as much as 80 feet above the surrounding landscape, the ridges are composed primarily of glaciofluvial sediments, ranging from thin silt beds to crossbedded medium gravels.

The hills may be kames that formed as meltwater exploited zones of weakness in the stagnating late Woodfordian Des Moines lobe ice. The ridges are roughly parallel to the direction of ice movement in the area and are immediately downstream from a series of Precambrian granite knobs. The granite would have been more resistant than the older drifts and the Cretaceous shales over which the ice moved, and may have disrupted the internal structure of the ice for some distance past the obstructions.

STOP 9

Title: Dakota Rose Granite Quarry



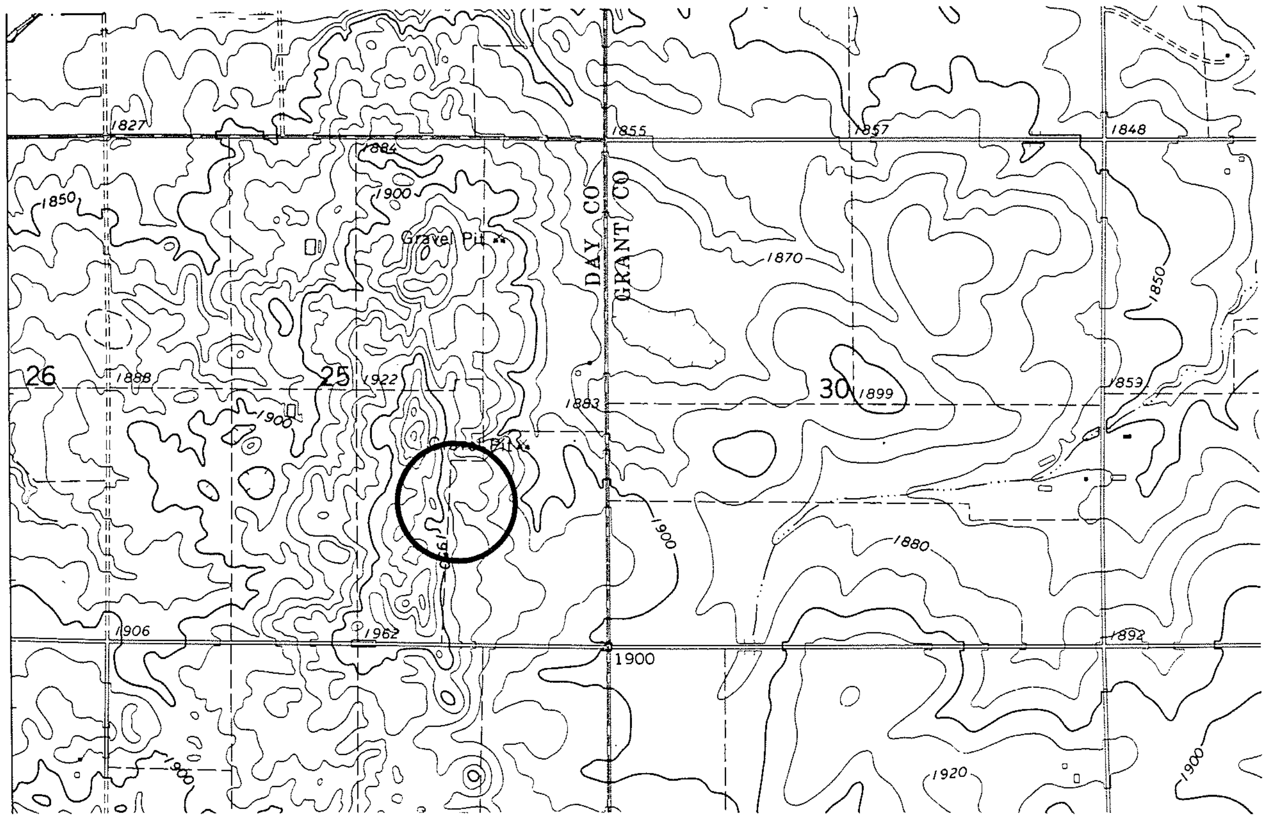
Location: SW¼NW¼SW¼ sec. 18, T. 120 N., R. 47 W., Grant County, South Dakota; Milbank East 7½-minute topographic quadrangle. C.I. = 10'. Granite quarry operated by the Dakota Granite Company.

At this stop we see evidence of glacial erosion, with a bit of bedrock geology for variety. At this site, as well as others in the area, the Precambrian basement rises to elevations of nearly 1,100 feet, providing the only naturally occurring bedrock out-crops. These knobs also stood as higher ground when the region was covered by Late Cretaceous seas. Fossil-bearing, marly shale, siltstone, and arkosic sandstone unconformably overlie the Precambrian Milbank granite. Vertebrate remains, particularly shark teeth and fish scales, are common in sediments preserved between the knobs of exfoliating granite (Shurr and others, 1987).

Glacial erosion has removed most of the fossiliferous material, and has also stripped off the thick saprolite developed on the Precambrian rocks in the region. Preservation of the preglacial sediments is limited to the leeward sides of the higher knobs. The up-ice sides of the knobs are heavily abraded and have well-developed striations, trending to the southeast. The trend of the striae is roughly parallel to those of the sub-New Ulm till boulder pavement, indicating that they are the product of the most recent ice advance (Des Moines lobe) into the area.

STOP 10

Title: Thurman Gravel Pit

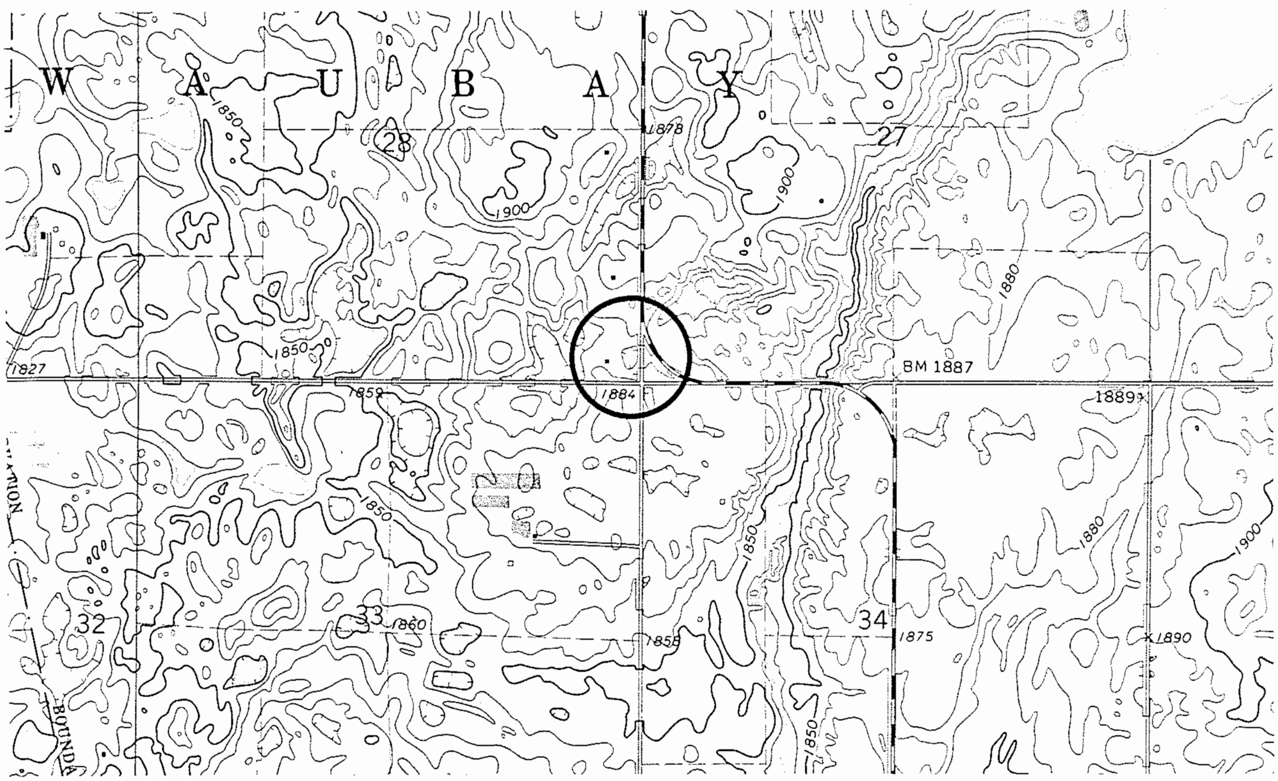


Location: SE¼NW¼SE¼ sec. 25, T. 121 N., R. 53 W., Reservation, Day County, South Dakota; Lonesome Lake 7½minute topographic quadrangle. C.I. = 10'. Gravel pit in the east side of the Dakota moraine, about ½ mile west of the Day and Grant County line.

At this stop we will have a chance to examine the interior of the distal edge of the Dakota moraine. For a length of some 30 miles, from its confluence with the Bemis/Altamont moraines to the area west of Watertown, the outer edge of the moraine is marked by a sharp linear ridge. Numerous drainage channels and outwash plains are found to the east and moderate relief stagnation moraine occurs to the west. The proximal edge of the moraine is often poorly defined. Composed mostly of sorted sediments, this ridge apparently formed as an ice-contact feature along the edge of the James lobe. A possibly comparable feature has been described adjacent to the St. Croix moraine in central Minnesota by Norton (1982).

STOP 11

Title: Soil genesis in prairie potholes.

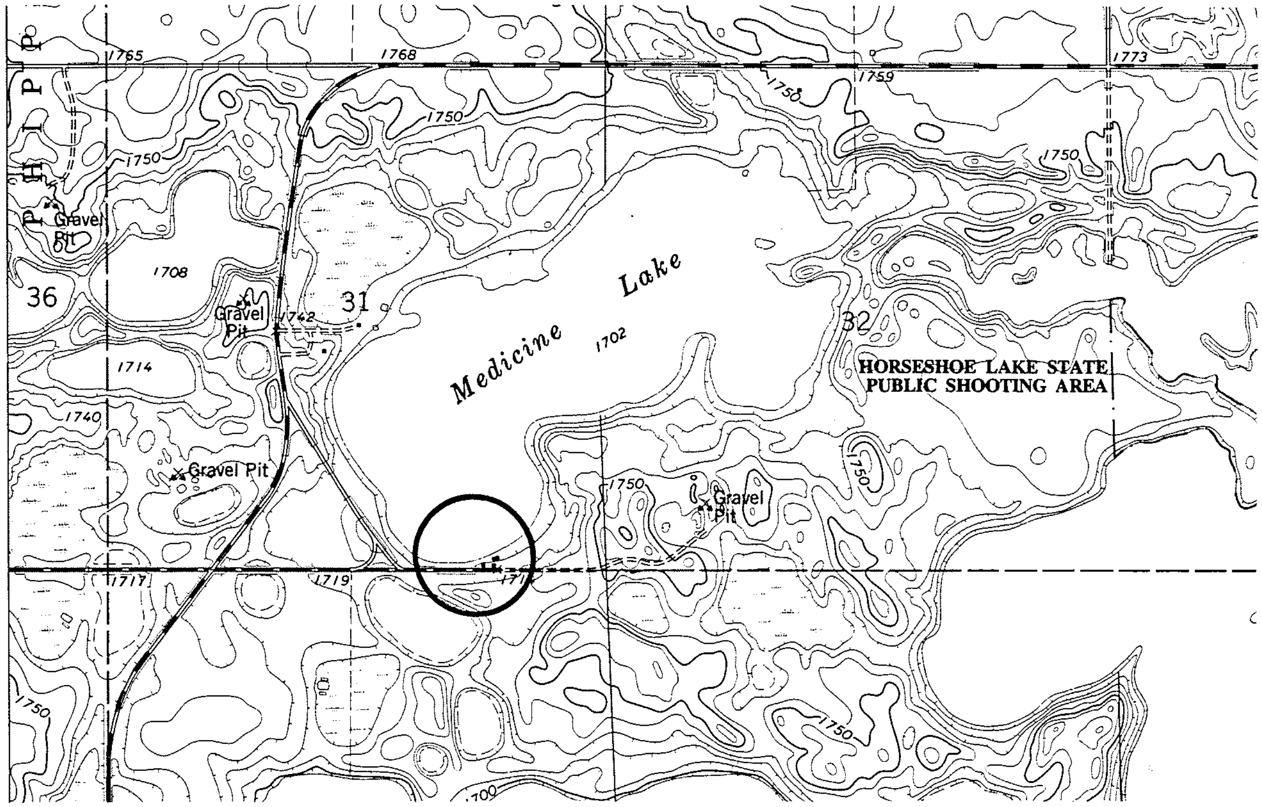


Location: SE$\frac{1}{4}$SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 28, T. 123 N., R. 53 W., Reservation, Day County, South Dakota; Enemy Swim West 7$\frac{1}{2}$-minute topographic quadrangle. C.I. = 10'. Small pothole on the west side of road.

James B. Millar, with the USDA - Soil Conservation Service, will present a discussion on the role of hydrology and topography in soil development in the area.

STOP 12

Title: Medicine Lake



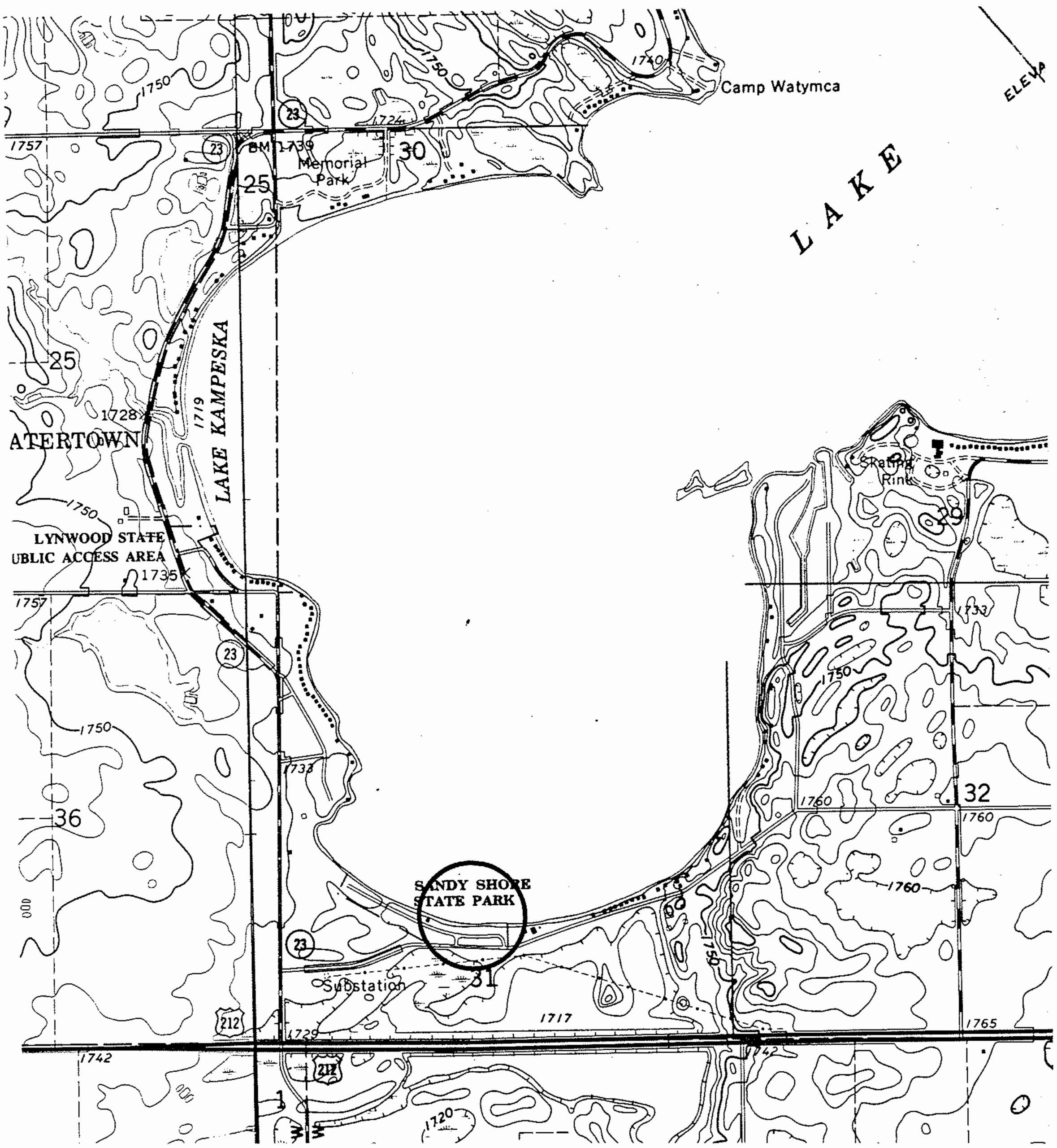
Location: SW¼SE¼SE¼ sec. 31, T. 118 N., R. 54 W., Codington County, South Dakota; Kampeska 7½-minute topographic quadrangle. C.I. = 10'. We will be stopping at Reeve's Resort on the south side of Medicine Lake.

Medicine Lake is one of a series of kettle lakes found in an area of collapsed, late Woodfordian outwash. A lack of external drainage has resulted in elevated levels of dissolved solids in many of these lakes. Mineral constituents, derived from the surrounding carbonate- and shale-bearing tills, are concentrated by evaporation in the lakes. Medicine Lake typically contains between 25,000 and 80,000 parts per million (ppm) total dissolved solids. The local record for "bad water" is 343,935 ppm for Cooley Lake water in September, 1969 (Stockdale, 1971).

A 13.4 meter sediment core recovered from the center of the main basin of the lake has been analyzed by Radle (1981). A radiocarbon age of 10,940 ± 135 yr B.P. (WIS-1227) from wood fragments recovered from the core provides a minimum age for the lake. Results of the pollen analysis of this core and related topics will be presented at the stop.

STOP 13

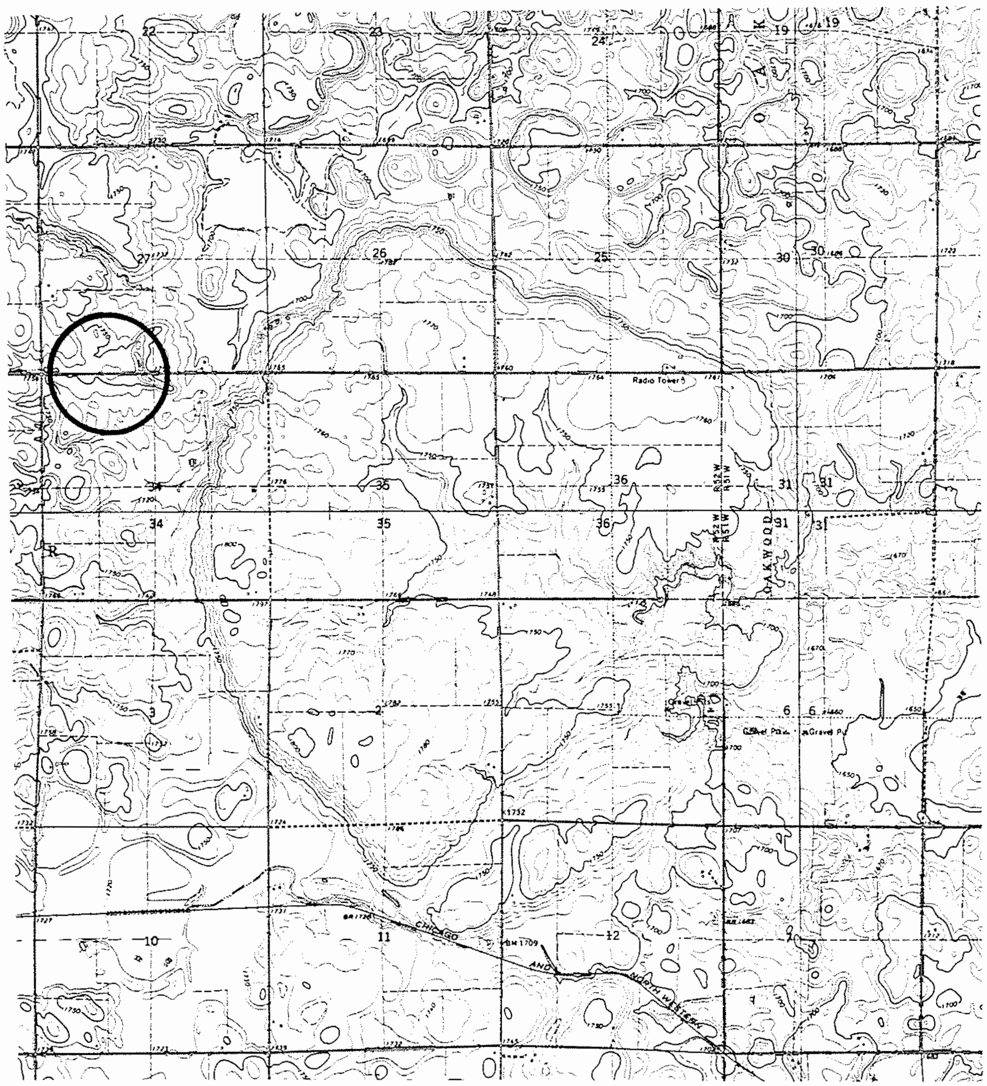
Title: Sandy Shore State Recreation Area



Location: NE¼SE¼SW¼ sec. 31, T. 117 N., R. 53 W., Codington County, South Dakota; Watertown West 7½-minute topographic quadrangle. C.I. = 10′. Park is located at the southwest end of Lake Kampeska.

STOP 14

Title: Ice-walled Lake Plain

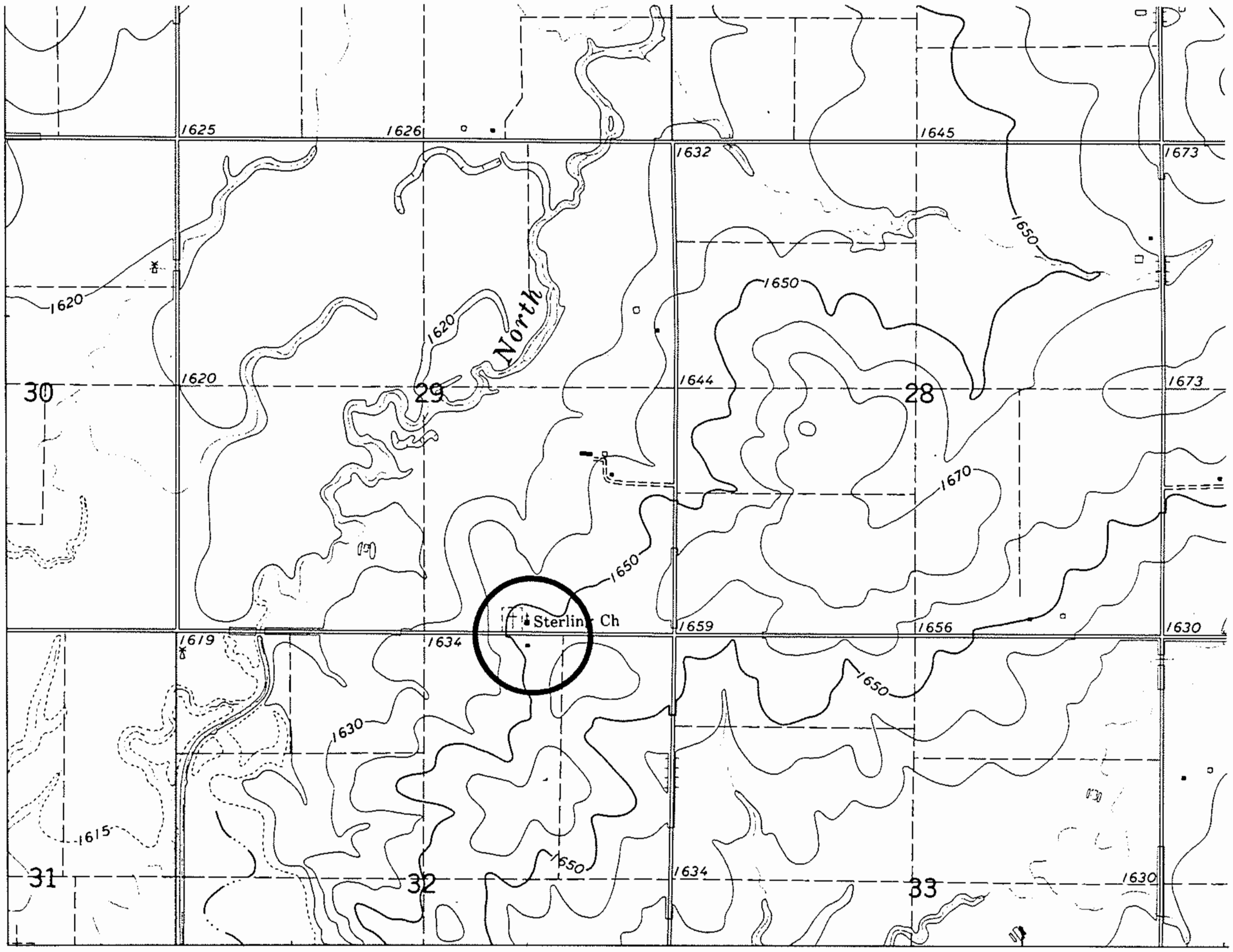


Location: SW$\frac{1}{4}$SE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 27, T. 111 N., R. 52 W., Brookings County, South Dakota; Arlington NE 7$\frac{1}{2}$-minute topographic quadrangle. C.I. = 10'. We will observe the feature from a small rise on the north side of Brookings County Road 8.

From this stop we have a view of one of the largest ice-walled lake plains in the State. Covering an area of some 4 square miles, this feature is one of many such stagnation features found in the area west of the Dakota moraine.

STOP 15

Title: Brookings Till Plain



Location: SE¼SW¼SE¼ sec. 29, T. 111 N., R. 50 W., Brookings County, South Dakota; Brookings NE 7¼-minute topographic quadrangle. C.I. = 10'. We will stop on the grounds of Sterling Church, located on the north side of Brookings County Road 8.

At this stop we will discuss the various lines of evidence in support of the Brookings till plain. Sterling Church is located near the crest of one of the low-relief, northeast-southwest trending uplands separated by late Wisconsin outwash channels. Although no test-hole data are available for this location, holes drilled in similar positions on other ridges encounter thick, composite oxidized zones, some in excess of 100 feet. A piece of wood recovered from the base(?) of this sequence in southeastern Brookings County yielded a radiocarbon age of >30,000 yr B.P.

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