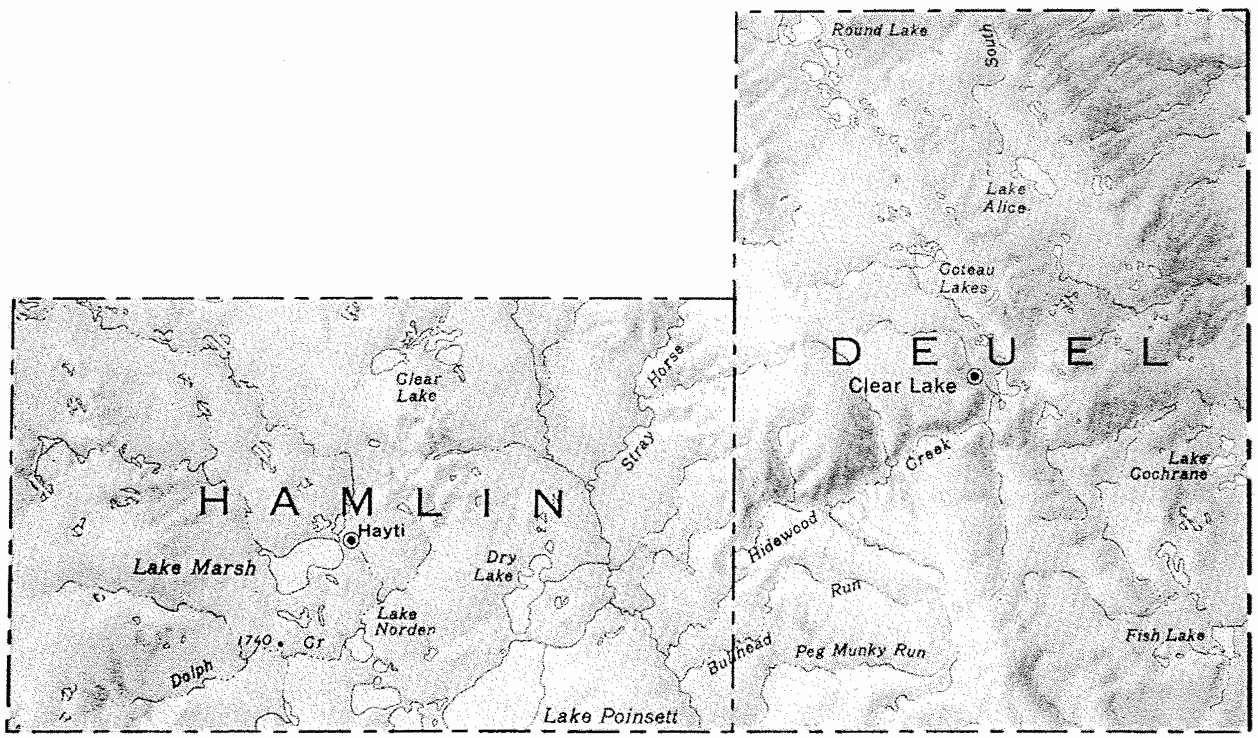
Bulletin 27

Geology and Water Resources of Deuel and Hamlin Counties, South Dakota Part 1: Geology



by Dennis R. Beissel and Jay P. Gilbertson

Prepared in cooperation with the United States Geological Survey,
East Dakota Conservancy Sub-District, and Deuel and Hamlin Counties, South Dakota

DEPARTMENT OF WATER AND NATURAL RESOURCES
SOUTH DAKOTA GEOLOGICAL SURVEY – 1987

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

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Part I: GEOLOGY

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Science Center
University of South Dakota
Vermillion, South Dakota

1987

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ABSTRACT

Deuel and Hamlin Counties are located in northeastern South Dakota and have a combined area of 1,156 square miles. The major physiographic feature in the area is the Coteau des Prairies, which is characterized by glacial-moraine topography.

Pre-Pleistocene deposits are found only in the subsurface and consist of Cretaceous shales, limestones and sandstones lying on top of the crystalline Precambrian surface.

Pleistocene age deposits everywhere overlie the bedrock and average 500 feet thick. The deposits are both glacial and nonglacial and consist of till, outwash, lake sediments, and loess. Holocene age alluvial and colluvial sediments were found on recent stream flood plains and hillsides, respectively.

The Pleistocene deposits have been divided into three complexes, I, II, and III, oldest to youngest respectively. Age relationships are based on superposition, weathering zones (oxidation) and a radiocarbon date of wood cuttings from a test hole. Drift Complex III encompasses the entire surface of the two Counties and is late Wisconsin in age--younger than 23,000 radiocarbon years before present (rybp).

Economic resources include large reserves of ground and surface water. Sand and gravel deposits are abundant in the two-County area. There are no metallic or fossil-fuel resources within the study area.

INTRODUCTION

Purpose

The geology and water-resources investigation of Deuel and Hamlin Counties was made possible by the combined efforts of the South Dakota Geological Survey, United States Geological Survey, East Dakota Conservancy Sub-District, and the Deuel and Hamlin County Commissioners. The goals of this investigation were to locate and evaluate the mineral and water resources of the two Counties and to provide a basic geologic and hydrologic data framework for further exploration and development of the natural resources of the area.

The findings of the investigation are published in five parts:

1. Sand and gravel resources of Deuel County, South Dakota: South Dakota Geological Survey, Information Pamphlet no. 9, 1976, by Wayne Schroeder.

2. Sand and gravel resources of Hamlin County, South Dakota: South Dakota Geological Survey, Information Pamphlet no. 10, 1976, by Wayne Schroeder.

3. Major aquifers in Deuel and Hamlin Counties, South Dakota: South Dakota Geological Survey, Information Pamphlet no. 11, 1976, by Jack Kume.

4. Geology and water resources of Deuel and Hamlin Counties, South Dakota, Part I: Geology: South Dakota Geological Survey, Bulletin no. 27, 1987, by Dennis R. Beissel and Jay P. Gilbertson.

5. Water resources of Deuel and Hamlin Counties, South Dakota: U.S. Geological Survey, Water-resources investigations report 84-4069, 1985, by Jack Kume.

Physiography

Deuel and Hamlin Counties include an area of 1,156 square miles in eastern South Dakota (fig. 1). Deuel County contains 636 square miles and Hamlin County, 520 square miles. Most of Deuel and Hamlin Counties are in the Coteau des Prairies division of the Central Lowland Physiographic Province (Fenneman, 1931). About 15 square miles of extreme northeastern Deuel County are in the Minnesota River-Red River Lowland division of the same province.

The Coteau des Prairies is one of the more impressive topographic features in South Dakota. It is a massive, flatiron-shaped highland some 200 miles in length extending from southeastern South Dakota to extreme southern North Dakota and is 75 miles in width across east-central South Dakota. The eastern escarpment of the Coteau des Prairies in Deuel County has a slope of approximately 80 feet per mile. The western slope, in Clark County, drops at a rate of about 25 feet per mile.

The surface of the Coteau des Prairies is characterized by glacial-moraine topography which has a general hummocky appearance formed by the action and subsequent melting of glacial ice. Major topographic features have a northwest-southeast trend, paralleling the Coteau des Prairies escarpments. The axis of the Coteau des Prairies is marked by the Big Sioux River, which originates in southwestern Roberts County, flows south through Hamlin County, and eventually joins the Missouri River near Sioux City, Iowa. Erosional processes of the Big Sioux River and its tributaries have formed an integrated drainage system in eastern Hamlin and western Deuel Counties (fig. 2).

That part of Deuel County in the Minnesota-Red River Lowland is generally flat and underlain mostly by glaciolacustrine and glaciofluvial deposits. Several gravel ridges trending northwest-

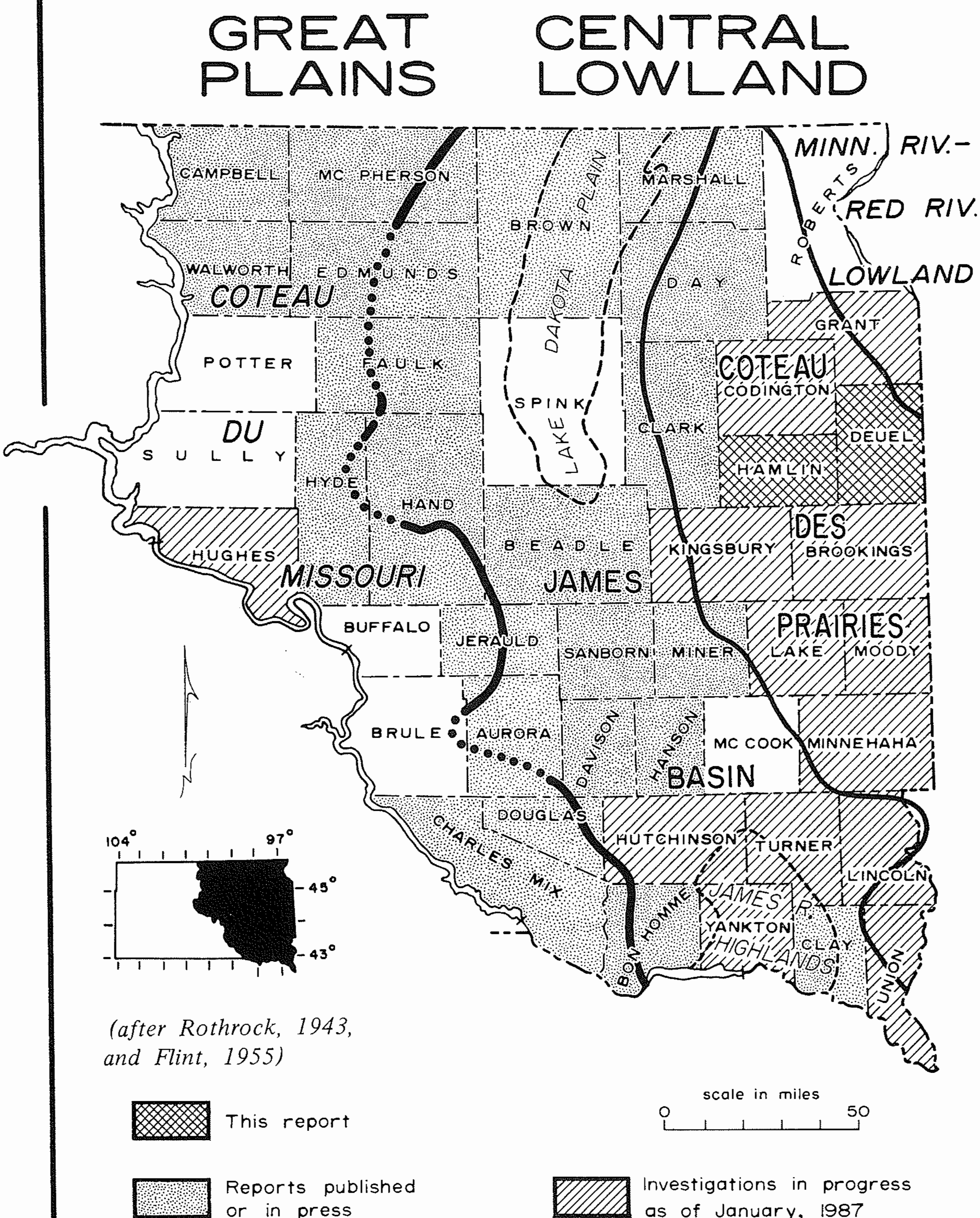
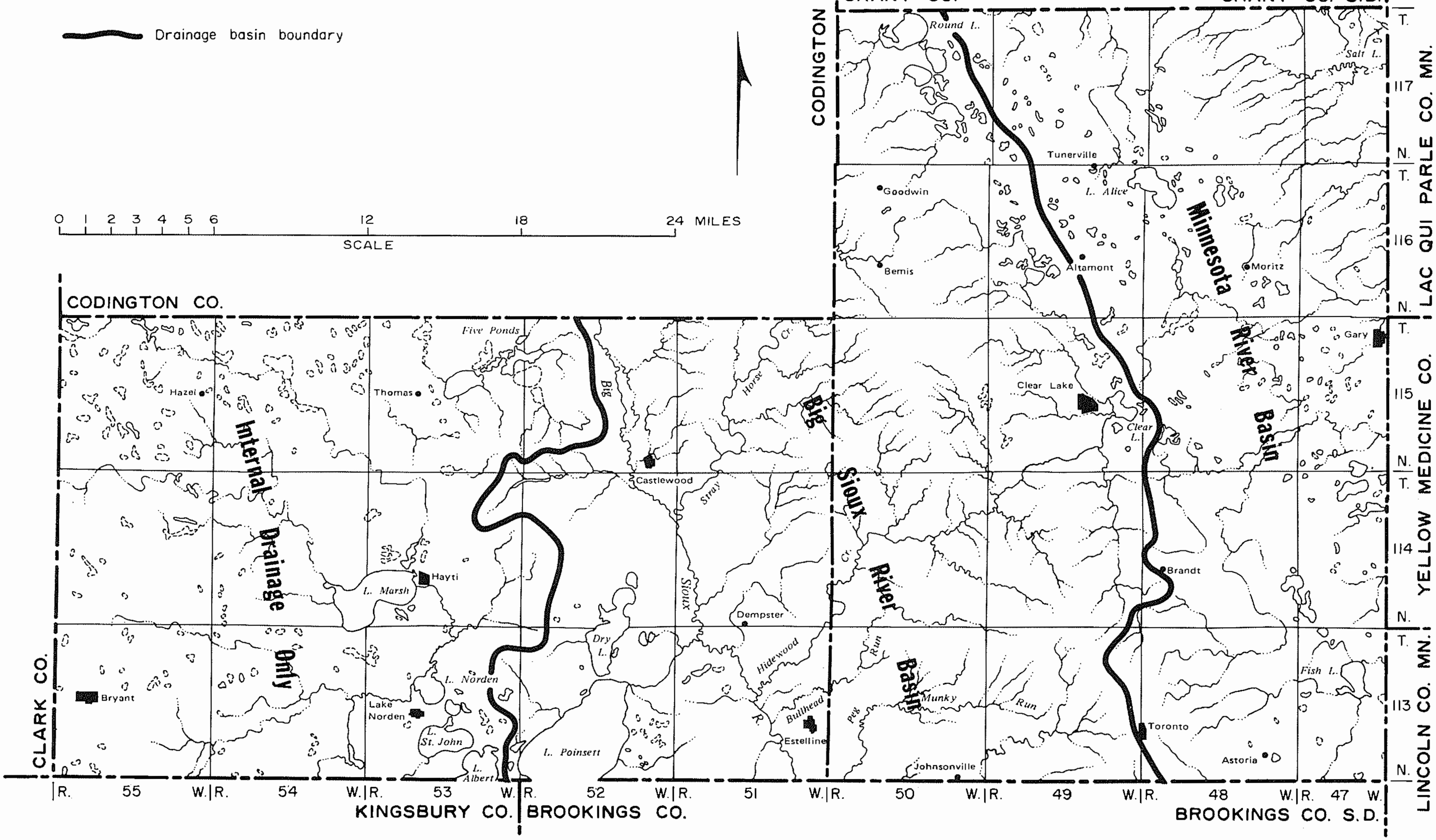


Figure 1. Index map of eastern South Dakota showing area of this report, status of county investigations, and major physiographic divisions.

Figure 2. Physiographic and drainage basin map of Deuel and Hamlin Counties.



southeast are present in this area. The eastern half of Deuel County drains east into the Minnesota River (fig. 2).

Drainage in western Hamlin County is nonintegrated and does not directly contribute to any major stream system (fig. 2).

The highest point in the study area is at an elevation of just over 2,040 feet above mean sea level on the Bemis moraine south of Goodwin in Deuel County. The lowest point is Salt Lake in extreme northeastern Deuel County at an elevation of 1,142 feet.

Previous Investigations

The earliest published physical description of the Deuel and Hamlin County area was by George Catlin, who traveled through the area in 1835 (Flint, 1955, p. 4). The first person to map the glacial deposits of the area was Warren Upham (1880, 1881, 1884). Chamberlin (1883), using the work of Upham and J. E. Todd along with his own observations, traced some of the moraine systems in eastern South Dakota. Todd (1885, 1894, 1896, 1899, 1900) published many papers on the geology of eastern South Dakota, directed mainly at topographic features and surficial glacial deposits. Leverett (1922a and b, 1932) did reconnaissance work in the area and Rothrock (1934, 1943) studied the glacial deposits near Deuel and Hamlin Counties. Flint (1955) investigated the Pleistocene geology of eastern South Dakota, which provided a framework for more recent studies.

Following Flint's work, the Estelline, Hayti, and Watertown 15 minute geologic quadrangles were mapped by Steece (1957a, b, c,) and the Henry 15 minute quadrangle was mapped by Tipton (1958). All of these include parts of Deuel and Hamlin Counties. Matsch, Rutford, and Tipton (1972) included the two-County area in a discussion of the Quaternary geology of northeastern South Dakota and southwestern Minnesota.

Several water-resources studies have been completed in Deuel and Hamlin Counties. Erickson (1954) investigated bedrock aquifer artesian conditions in east-central South Dakota. Steece (1958) studied the geology and shallow ground water resources along the Big Sioux River Valley in the Watertown-Estelline area and Barari (1971) investigated the hydrology of Lake Poinsett in Hamlin County. Jorgensen (1965a and b) conducted ground water supply studies for the towns of Bryant and Lake Norden and Barari (1972) did the same for Hazel in Hamlin County. Similar projects are currently in progress for the cities of Hayti and Clear Lake. All of the water-resource studies contain basic data which contributed to the groundwork for this investigation.

General Field Methods

Most of the information contained in this report was obtained during the summer field seasons of 1972, 1973, and 1974. The geology was mapped on aerial photographs having a scale of approximately 1:70,000 (about 1 inch = 0.9 miles). The data were then transferred to a base map with a scale of 1 inch = 1 mile. The base map was a standard South Dakota Department of Transportation map reduced to a smaller size for this report.

Geologic data were collected from inspection of natural and man-made outcrops of rock material and from information derived from hundreds of test holes and wells. Air-photo interpretation was aided by 7 1/2 minute topographic maps and unpublished soils maps. Subsurface information was obtained from examination of well cuttings and geophysical logs of rotary and power auger test holes drilled by the South Dakota and United States Geological Surveys. Additional information was obtained from well records of private drillers and other federal and state agencies.

Acknowledgements

The investigation and preparation of this report were performed under the supervision of Duncan J. McGregor and Merlin J. Tipton, State Geologists. The writer wishes to thank the entire staff of the South Dakota Geological Survey for their advice and assistance during the project. Special thanks to Cleo M. Christensen, Lynn Hedges, Jack Kume, and Merlin J. Tipton for their participation in many field conferences and discussions related to the project. The assistance in the field of Steve Whittet, Carl Cripe, Ed Houser, Suzanne Kairo, Julie Simon, and Gail Wilkinson is greatly appreciated as are the efforts of the drillers: Lloyd Helseth, Millard Thompson, Jr., Monte Nienkerk, and Lyle Steffen.

The study was initiated at the request of the Deuel and Hamlin County Commissioners. The cooperation of the Commissioners, County Extension Agents, and the residents of the two Counties is gratefully acknowledged.

Financial assistance for the project was provided by the South Dakota Geological Survey, United States Geological Survey, East Dakota Conservancy Sub-District, and Deuel and Hamlin Counties.

STRATIGRAPHY

Pre-Pleistocene Deposits

Stratigraphic nomenclature used in this report conforms to that accepted by the South Dakota Geological Survey (Agnew and

Tychsen, 1965) and to the Code of Stratigraphic Nomenclature (American Commission on Stratigraphic Nomenclature, 1961).

Table 1 lists all of the pre-Pleistocene deposits that are present in Deuel and Hamlin Counties. The youngest deposit is listed at the top, the oldest at the bottom.

TABLE 1

General pre-Pleistocene stratigraphic section in Deuel and Hamlin Counties

TIME-STRATIGRAPHIC UNITS	ROCK UNITS
Cretaceous System	
Upper Cretaceous Series	Montana Group
	Pierre Shale
	Colorado Group
	Niobrara Marl
	Carlile Shale
	Greenhorn Limestone
	Graneros Shale
Upper and Lower Cretaceous Series	
	Dakota Formation
Precambrian	
	Metamorphic and Igneous rocks

No outcrops of pre-Pleistocene rocks were found in the Deuel and Hamlin County area.

Precambrian

The only known test hole drilled to the Precambrian rocks in the study area was the Coteau Test no. 3, SW SE SW sec. 36, T. 113 N., R. 48 W., in southeastern Deuel County. Twenty feet of Precambrian "wash," consisting of sand, were penetrated at a depth of 1,060 feet. Below this sand, 16 feet of metamorphic chlorite schist were penetrated. The surface of the Precambrian at this location is at an elevation of 800 feet above mean sea level (MSL). Geophysical surveys suggest that granitic rocks, similar to those found near Milbank in Grant County, would be found in the northwestern portions of both Counties (Lidiak, 1971, p. 1413).

Cretaceous Rocks

Bedrock in Deuel and Hamlin Counties is composed primarily of Cretaceous age shales, marls, sandstones, and limestones (table 1).

DAKOTA FORMATION

The Dakota Formation was first described by Meek and Hayden (1862) from an exposure in Dakota County, Nebraska. The formation is composed of varicolored, fine- to medium-grained, friable to well consolidated sandstones interbedded with siltstone and shale. The maximum known thickness of the Dakota in the study area is 115 feet found in the Bryant City Railroad Well, SW SW SW sec. 17, T. 113 N., R. 55 W. The formation top is at an elevation of 600 feet above MSL. A thickness of 20 feet is recorded in Coteau Test no. 3 and the formation top is at an elevation of 820 feet. A brownish-gray, fine-grained, consolidated, noncalcareous, sandstone interbedded with silt and shale is recorded in test hole DR-7310, SW SW SW SW sec. 4, T. 117 N., R. 47 W., in northeast Deuel County. The sandstone is 36 feet thick and the top is at an elevation of 785 feet above MSL. This sandstone may be equivalent to the Dakota Formation. Schoon (1971) provides a complete discussion of the stratigraphy and hydrology of the Dakota Formation in South Dakota.

GRANEROS SHALE

The Graneros Shale overlies the Dakota Formation in Deuel and Hamlin Counties. The Graneros is a medium to dark gray, silty, noncalcareous shale interbedded with thin silt and sand layers. It was first described by Gilbert (1896) from an exposure near Graneros Creek, Pueblo County, Colorado. The Graneros is 158 feet thick in the Bryant City Railroad Well and 50 feet thick in Coteau Test no. 3. A brownish-gray, shaley, noncalcareous clay 18 feet thick is recorded in test hole DR-7310 in northeast Deuel County.

GREENHORN LIMESTONE

Gilbert (1896) first described and named the Greenhorn Limestone from an exposure near Greenhorn Station, Colorado. The Greenhorn is a white to light gray, fossiliferous marl containing shell fragments, with _Inoceramus labiatus_ as the most common fossil. The Greenhorn has a characteristic contrasting kick on gamma and electric logs and is thus a good stratigraphic marker bed. The Greenhorn is 27 feet thick in Coteau Test no. 3 and 34 feet thick in the Bryant City Railroad Well. A brown, silty, soft, calcareous clay 19 feet thick is recorded in test hole DR-7310 overlying the Graneros Shale (?) and may be equivalent to the Greenhorn in northeast Deuel County.

CARLILE SHALE

The Carlile Shale was first described and named by Gilbert (1896) from an exposure near Carlile Spring and Carlile Station, Colorado. Carlile Shale overlies the Greenhorn Limestone and consists of medium gray to black, noncalcareous, fissile shale. It is 237 feet thick in Coteau Test no. 3 and 184 feet thick in the Bryant City Railroad Well. One hundred thirty-seven feet of soft, gray shale was penetrated in test hole DR-7310 in Deuel County, beginning at an elevation of 959 feet above MSL.

Bedrock shown underlying the glacial deposits (fig. 3) in northeastern Deuel County is thought to be the Carlile Shale.

No evidence of the Codell Sandstone member of the Carlile Shale was found during test drilling.

NIOBRARA MARL

The Niobrara Marl overlies the Carlile Shale in northeast Deuel County (fig. 3). Meek and Hayden (1862) first described the Niobrara Marl from an exposure near the mouth of the Niobrara River in Nebraska, however, no type section has been designated for this formation. Total thickness of the Niobrara is 77 feet in Coteau Test no. 3 and 138 feet in the Bryant City Railroad Well.

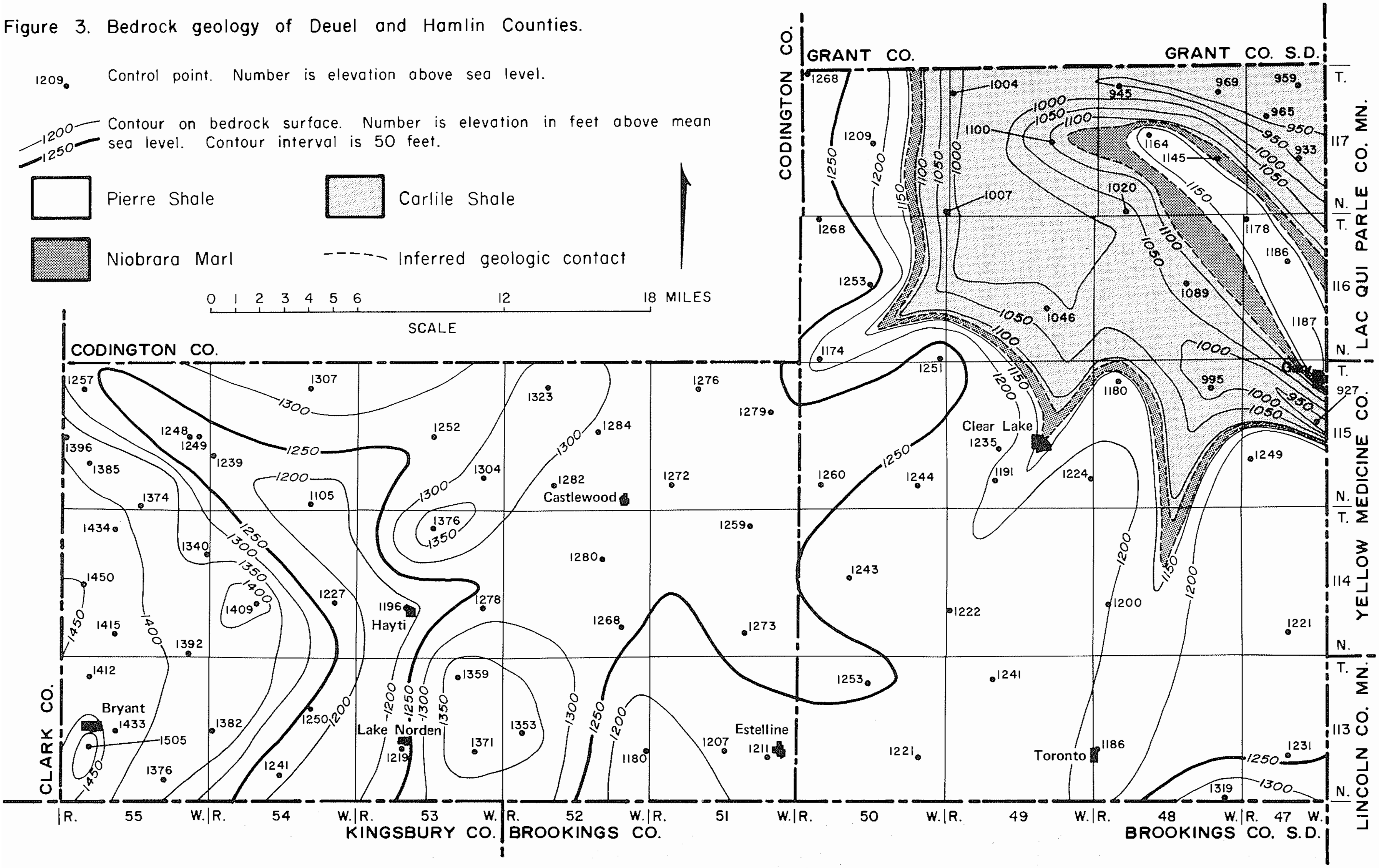
Several test holes drilled for this study encountered a light gray, silty, calcareous clay with drilling characteristics and cuttings similar to those found in known areas of Niobrara outcrops and subcrops. The calcareous clay is found in Deuel County between elevations ranging from 1,100 to 1,140 feet above MSL.

PIERRE SHALE

The Pierre Shale is the most extensive bedrock formation in contact with the base of the glacial drift in the Deuel and Hamlin County area (fig. 3). During test drilling, the Pierre was described as a light gray to black, greasy clay with some bentonite beds.

Pierre Shale was first named the Ft. Pierre group by Meek and Hayden (1862) for exposures along the Missouri River, but was shortened to Pierre Shale by Darton (1896). The Pierre Shale is subdivided into members, but these have not been differentiated for this report. Eroded Pierre is 362 feet thick in the Bryant City Railroad Well and has been completely removed by erosion in parts of northeast Deuel County. The surface of the Pierre as shown in figure 3 is the result of extensive glacial and glaciofluvial modification.

Figure 3. Bedrock geology of Deuel and Hamlin Counties.



Tertiary Deposits

No deposits of Tertiary age have been conclusively identified in Deuel or Hamlin Counties. In southwestern Hamlin County, some dark gray to black silts and clays were found at the base of the glacial drift and overlying Cretaceous bedrock. Well cuttings of this material have the appearance of alluvium derived from Pierre Shale. In contrast, most of the glaciofluvial deposits found at the base of the drift were fine, light gray silts or coarse gravel. However, there is not sufficient evidence to call these dark silts and clays Tertiary in age.

Pleistocene Deposits

Pleistocene age deposits completely blanket the bedrock surface in Deuel and Hamlin Counties (pl. 1). These deposits are composed of a complex sequence of glacial drift averaging 500 feet in thickness. Test hole DR-7308, SE SE SE SE sec. 36, T. 117 N., R. 50 W., penetrated 878 feet of Pleistocene deposits overlying the bedrock in northwestern Deuel County.

The glacial deposits have been divided into three drift sheet complexes, and labeled Drift Complex I, II, and III, from oldest to youngest (pl. 2). The divisions were based on the presence of two buried oxidized drift zones, and till characteristics. Each drift complex probably represents a number of different glacial advances and retreats that took place over the course of a glacial period.

The upper drift, Drift Complex III, is late Wisconsin in age and represents the most recent period of glacial activity in the study area. Deposits of Drift Complex III cover all of the surface of Deuel and Hamlin Counties. As there are no surface exposures of the two older drift complexes, it is difficult to assign them an exact age. A radiocarbon date on wood fragments found at the top of Drift Complex II indicates that is is no younger than 23,000 years before present (B.P.). With no additional dating information, Drift Complexes II and I will be referred to as pre-late Wisconsin.

Drift Complex I

Drift Complex I is the oldest sequence of glacial drift and, where present, overlies the bedrock. Distribution of Drift Complex I is shown on figure 4. Thickness of the drift is up to 350 feet and averages about 200 feet. Drift Complex I is divided into four basic units: basal outwash, till, interbedded outwash, and lake deposits.

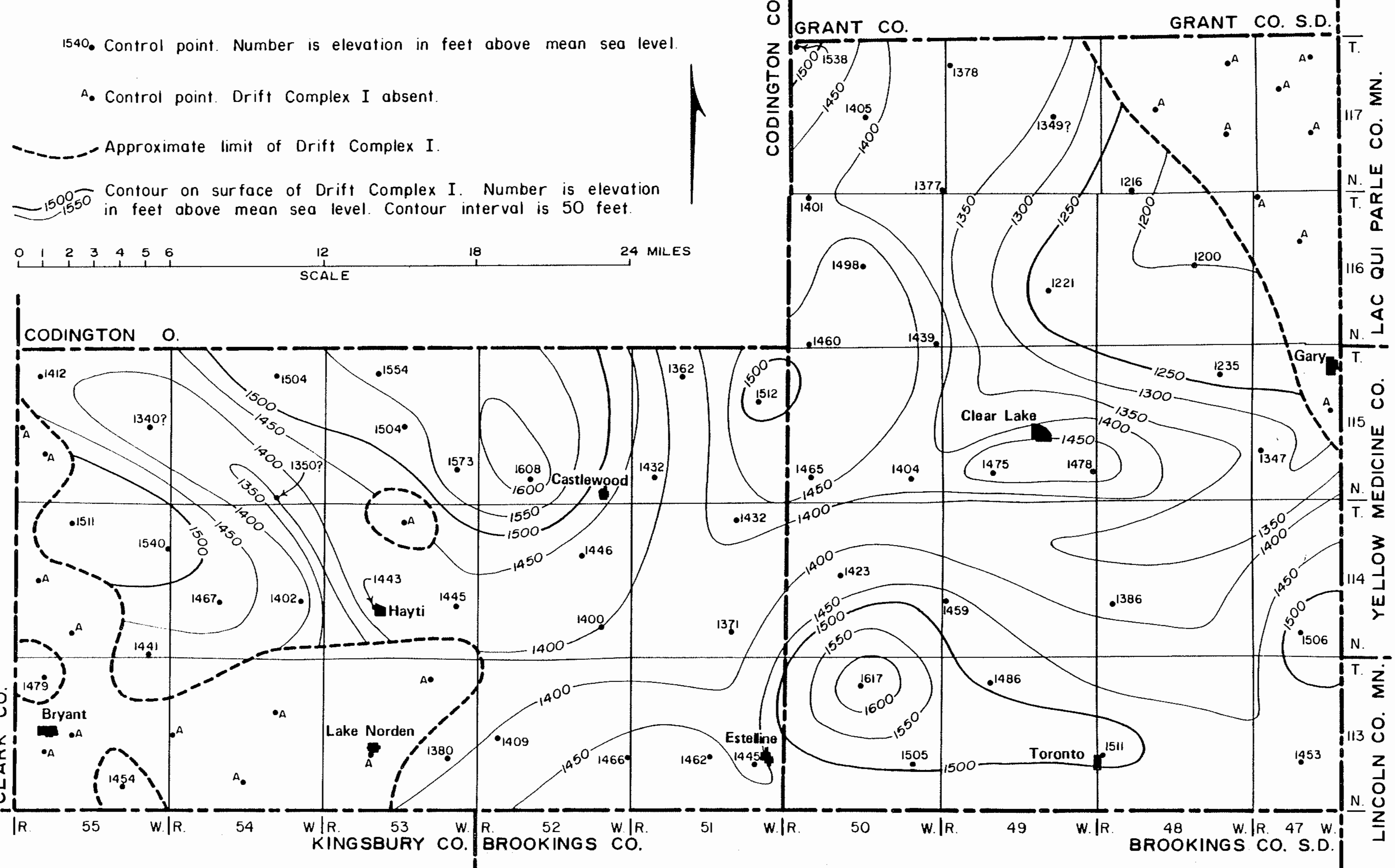


Figure 4. Distribution and inferred surface topography of Drift Complex I.

BASAL OUTWASH

Fine silt to coarse, gravel-size, glaciofluvial deposits were found at the base of Drift Complex I overlying the bedrock. The areal extent of this outwash coincides with that of Drift Complex I as shown in figure 4. Some basal fluvial deposits outside of this limit, particularly those found along bedrock channels, may be associated with Drift Complex I, but evidence to support this correlation was not found.

Drift Complex I basal outwash beds are up to 150 feet thick and generally consist of medium sand to coarse gravel composed of angular to subrounded grains of shale intermixed with limestone, dolomite, sandstone, and a variety of igneous and metamorphic rock fragments. Coal fragments are abundant at some locations.

Beds of brownish-gray to gray silt-size particles up to 100 feet thick are interbedded with the sand and gravel in bedrock lows and are lying on top of the coarser material in southeast Hamlin County. Here, the entire Drift Complex I sequence is represented by only the basal outwash unit.

TILL

Most of Drift Complex I is composed of shaley, silty, sandy, calcareous, clay till up to 290 feet thick. This till is gray to dark gray when unoxidized and brown to brownish-yellow when oxidized. Where present, the oxidized zone in the upper part of the Drift Complex I till ranges up to 75 feet thick and averages approximately 40 feet. Distribution of the till unit coincides generally with the limits of Drift Complex I.

INTERBEDDED OUTWASH

Beds and lenses of silt to coarse, gravel-size outwash occur within the till unit of Drift Complex I. These outwash deposits range up to 30 feet in thickness. There are fewer beds of outwash within the Drift Complex I till than in the till units of the other two younger drift complexes.

LAKE DEPOSITS

The contact between Drift Complex I and overlying deposits is marked in places by a sequence of fine silts and clays overlain by till. These deposits are lacustrine in origin, although their exact age is uncertain. Some of the clays are oxidized and correlate with the oxidized zone in the till unit.

Drift Complex II

Drift Complex II is the middle drift unit shown on the cross sections (pl. 2). It ranges up to 345 feet in thickness and averages about 150 feet. It is more extensive than Drift Complex I and can be found everywhere in the subsurface of the two-County area except in extreme east and northeast Deuel County (fig. 5). The lower limit of Drift Complex II is marked by contact with the oxidized zones and lake deposits of Drift Complex I but is underlain by bedrock where Drift Complex I is absent. The upper surface is shown by contact with the late Wisconsin drift (pl. 2). Drift Complex II is divided into several lithologic units: basal outwash, till, interbedded outwash, and lake deposits.

BASAL OUTWASH

Clay to coarse gravel-size glaciofluvial deposits were found at the base of Drift Complex II overlying the bedrock in western Hamlin County and Drift Complex I in most of the other areas. The areal extent of the basal outwash unit coincides with that of Drift Complex II as shown on figure 5, except in that portion of Hamlin County mentioned above.

The basal outwash ranges up to 150 feet in thickness and generally consists of fine sand to coarse gravel composed of subangular and subrounded grains of limestone, dolomite, and shale with varying amounts of igneous and metamorphic rock fragments. Minor amounts of coal fragments are present in some areas. Clay and silt beds are interbedded with the sand and gravel in central and western Hamlin County.

The basal outwash unit of Drift Complex II represents the entire Drift Complex II sequence in parts of south-central Hamlin County. Test hole HR-7408, SW SW SW SW sec. 2, T. 113 N., R. 53 W., penetrated 115 feet of clay, sand, and gravel, of which the upper 50 feet were oxidized. Test hole HR-7315, SE SE SE SE sec. 26, T. 114 N., R. 52 W., penetrated 65 feet of basal outwash.

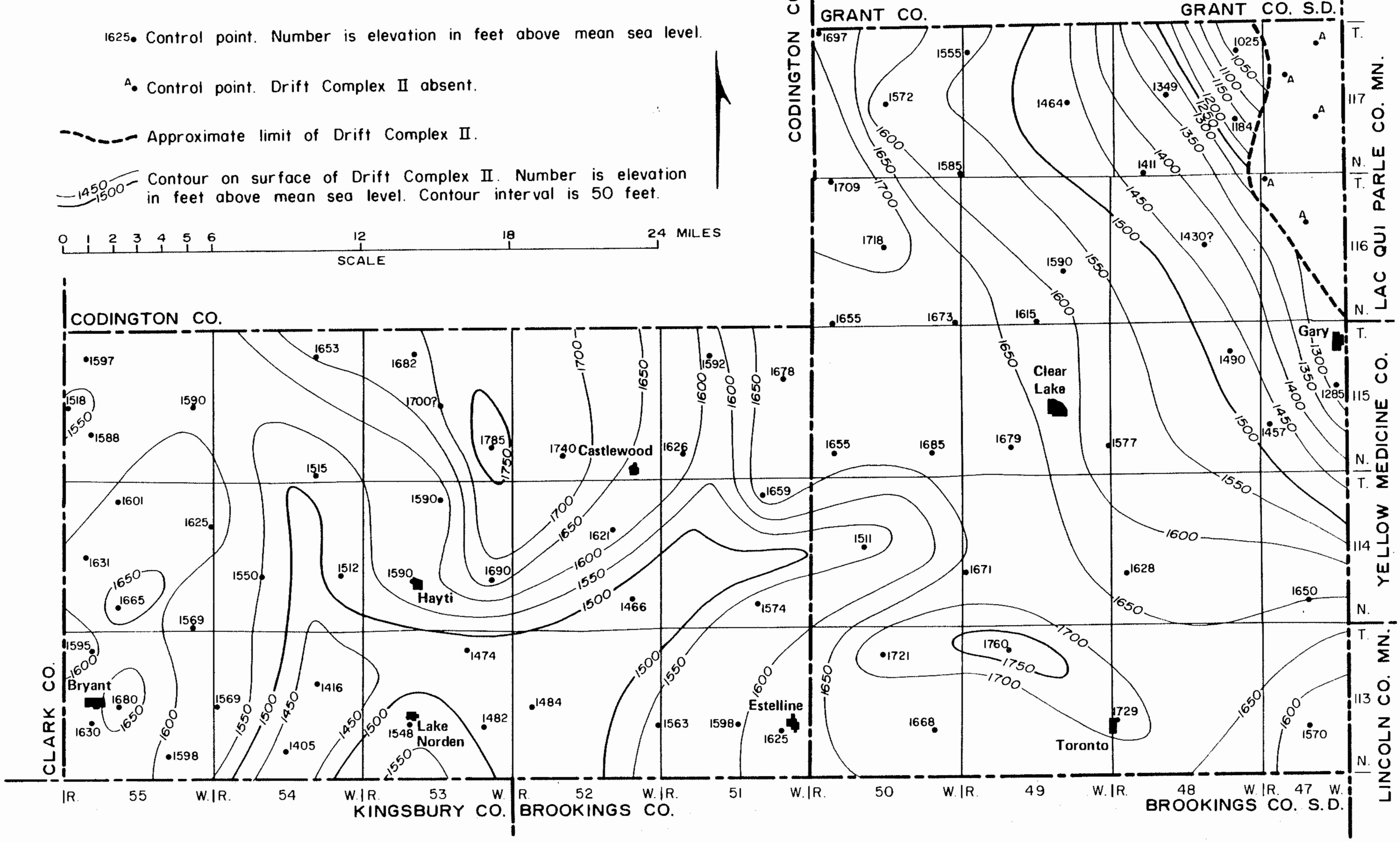
TILL

Most of Drift Complex II consists of a silty, sandy, pebbly, calcareous clay till up to 280 feet thick. The till is gray to olive colored when unoxidized and brown to yellow-brown when oxidized. Distribution of the till coincides with that of Drift Complex II (fig. 5). An oxidized zone in the upper part of the till is up to 100 feet thick and averages 50 feet where present.

INTERBEDDED OUTWASH

Silt to coarse gravel-size outwash lenses up to 30 feet thick occur within the till unit of Drift Complex II. The outwash is

Figure 5. Distribution and inferred surface topography of Drift Complex II.



generally composed of quartz, limestone, dolomite, and shale fragments with minor amounts of igneous and metamorphic rock grains.

LAKE DEPOSITS

The upper surface of Drift Complex II is marked in places by as much as 40 feet of calcareous lake clays overlain by till or outwash of late Wisconsin age. Although the clays are treated here as being glaciolacustrine, they may be associated with the interglacial period just prior to the late Wisconsin. Wood taken from one of these deposits was dated at 22,900±1,000 years B.P. (GX-3439). The wood was obtained from test hole HR-7316 (NE NE NE NE sec. 34, T. 114 N., R. 51 W.) at a depth of 125 feet in a silty gray clay interval. The log of the test hole is shown in figure 6.

Drift Complex III

Drift Complex III contains all of the late Wisconsin age glacial deposits in Deuel and Hamlin Counties. The bottom of Drift Complex III is in contact with the oxidized zone or inferred top of Drift Complex II or with the bedrock where older units are absent. Most of the surficial deposits of the study area are included in this complex. Drift Complex III has been divided into five basic units: basal outwash, till, interbedded outwash, surface outwash, and lake sediments.

BASAL OUTWASH

Discontinuous outwash deposits up to 70 feet thick were found in places at the base of Drift Complex III overlying the Drift Complex II unit. The outwash consists of fine sand to coarse gravel composed of shale, limestone, dolomite, and various igneous and metamorphic rock fragments. The basal outwash in northeastern Deuel County overlies the bedrock and consists of coarse sand to coarse gravel beds up to 75 feet thick composed of limestone, dolomite, and abundant granite fragments.

TILL

Most of Drift Complex III is composed of calcareous, silty, sandy, pebbly, clay-loam till which is up to 300 feet thick. The till is yellowish-brown when oxidized and dark gray when oxidized. The depth of oxidation in the till is as much as 40 feet and averages about 20 feet. In outcrop, the till is usually oxidized and finely jointed, with iron staining along the joints. The joints are sometimes filled with a fine gray silt. Secondary carbonate nodules and shale pebbles are present in most outcrops investigated during the study.

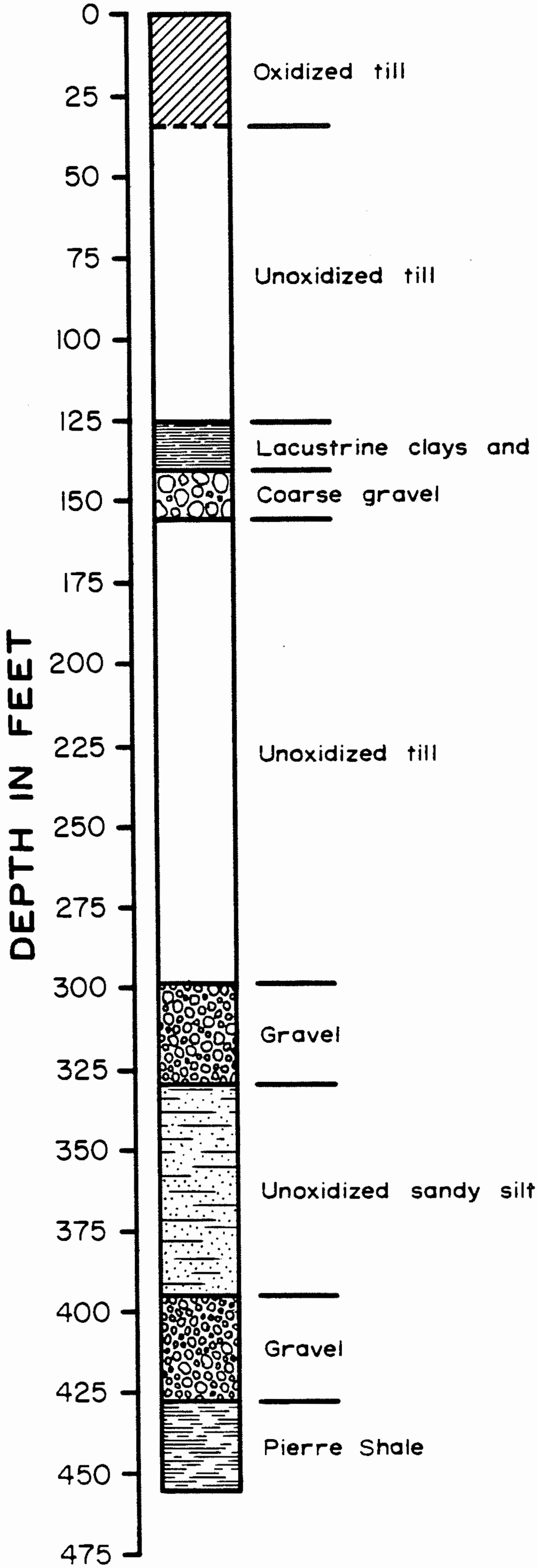
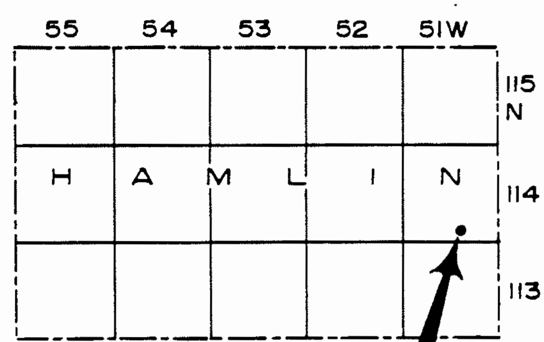


Figure 6. Log of test-hole HR-7316 in Hamlin County showing the interval from which dated wood cuttings were recovered.

Surface elevation is 1699 feet above mean sea level.

* indicates radiocarbon years before present.



Location: NE NE NE NE, sec. 34

INTERBEDDED OUTWASH

There are many discontinuous silt to coarse gravel-sized outwash beds within the till unit of Drift Complex III. These beds are up to 40 feet thick and average 10 feet in thickness. The sand and gravel is composed mostly of subrounded to angular shale, limestone, and dolomite fragments. These beds are very clayey in spots and grade laterally into the till unit.

SURFACE OUTWASH

Outwash silts, sands, and gravels are present at the surface throughout the study area (pl. 1). The surface outwash is associated with late Wisconsin glaciation and usually occurs as terrace, valley train, or collapsed deposits. Thickness of the surface outwash ranges up to 123 feet, but averages about 30 feet. It is locally overlain by loess and recent alluvium. The most extensive occurrence of the outwash is along the Big Sioux River Valley and its tributaries. There are several large areas of collapsed outwash west of Lake Poinsett in Hamlin County and west of Gary in Deuel County (pl. 1). A complete discussion of the surface outwash as an aquifer material may be found in Kume (1985).

GLACIOLACUSTRINE SEDIMENT

Glacial lake deposits of clay, silt, and minor amounts of sand occur in the study area, mostly near Lake Norden in Hamlin County and along Cobb Creek in south-central Deuel County. The lake beds are associated with collapsed topography, ice block basins, intermorainal valleys, and the eastern slope of the Coteau des Prairies. The lake deposits range in thickness up to 100 feet. X-ray analyses of the lake silts along Cobb Creek show that they are composed mostly of quartz, calcite, dolomite, and feldspar and contain from 10 to 35 percent clay.

Holocene Deposits

Post-glacial activity has produced a number of different deposits of Holocene age in the study area. However, only two of these (alluvium and colluvium) are of sufficient thickness and areal extent to be mapped as distinct units.

Alluvium

Deposits of stratified, gray to black, silt and clay, with minor amounts of sand and gravel, occur along the stream valleys and creek beds in the study area. This recent alluvium ranges up to 12 feet in thickness but averages only about 3 feet.

Colluvium

Colluvial deposits occur at the base and side of most steep slopes in the study area, but they were mapped as a separate unit only along the eastern escarpment of the Coteau des Prairies in northeast Deuel County. Colluvium is a weakly stratified mixture of silt, sand, gravel, and boulders in a matrix of clay. Accumulation of colluvial material started as the last stagnant ice melted and has continued to the present day.

DESCRIPTION OF LANDFORMS

Glacial

Almost all landforms found at the surface in Deuel and Hamlin Counties were formed as a direct result of late Wisconsin glaciation. This section of the report is intended to describe the distribution and form of the various geomorphic features in the area (pl. 1). A discussion of the age relationships between local and regional features is given in a later section of this report.

Stream Dissected Till Plain

The area mapped as stream dissected till plain is approximately bounded by the Bemis moraine on the east and the James Lobe Altamont moraine on the west. Glacial till, which locally contains lenses of silt, sand, and gravel, is the primary deposit within this area. The till is covered by up to 10 feet of loess on interfluves near the Big Sioux River Valley. Loess thickness in the entire area averages about 2 feet, with the thinnest deposits being near the moraine boundaries. Drainage within the till plain is well integrated with underfit streams flowing in the larger valleys. The area is traversed by several major meltwater channels as well as by ice-marginal channels. The Big Sioux River flows along the western edge of the area (pl. 1). Most constructional or depositional features directly related to action of glacial ice are either covered by loess or have been destroyed by headward erosion of streams. Small scale collapse or slump features have been observed in outcrops along Hidewood Creek in Deuel County.

End Moraines

End moraine is defined here as a ridge or series of ridges built at the margin of a glacier during a stillstand of active ice. Its surface may consist of ice-disintegration features. Three end moraines can be identified in the study area.

BEMIS MORAINE

The Bemis moraine was named by Leverett (1922b) for the outer moraine of the last major ice advance onto the east flank of the Coteau des Prairies. Regionally, the moraine extends from northeast South Dakota, through southwest Minnesota, and into central Iowa. It acts as a drainage divide between the Big Sioux and Minnesota Rivers (Matsch and others, 1972).

In Deuel County, the Bemis moraine is a broad ridge up to 8 miles wide trending northwest-southeast through the entire County. Its surface is well drained and has a patchy loess cover. The crest or highest part of the moraine consists of a series of linear disintegration ridges, the longest of which can be traced for about 3 miles (pl. 1). Contact between the distal slope of the Bemis moraine and the stream dissected till plain to the west is marked in most places by ice-marginal channels which are tributary to several large meltwater channels that transect the moraine. Most of the drainage on the moraine is off the proximal slope to the east. Near the town of Astoria, Deuel County, the moraine becomes very rugged with many knobs of silt, sand, and gravel.

ALTAMONT MORAINE

The Altamont moraine was named by Chamberlin (1883) for what he believed was the outermost moraine of the last (Wisconsin) glacial period. Like the Bemis moraine, it can be traced from the Coteau des Prairies in northeast South Dakota, through southwest Minnesota, south into Iowa, and back north into eastern Minnesota (Matsch and others, 1972). The moraine marks a recessional position of the Des Moines Lobe ice (Matsch, 1972).

In Deuel County, the Altamont moraine is a rough, hummocky, complex of knobs, kettles, and disintegration ridges up to 4 miles wide trending northwest-southeast (pl. 1). It is poorly drained with many potholes and sloughs. Although composed primarily of till, the surface of the moraine has many hills and ridges of silt, sand, and gravel. Contact between the distal slope of the moraine and deposits to the west is marked by collapsed outwash and stagnation moraine. The proximal slope of the moraine is in contact with stagnation moraine along its entire margin. The Altamont moraine is breached by a collapsed outwash channel in T. 117 N., R. 50 W., along the Deuel-Grant County boundary and by an outwash channel in T. 115 N., R. 49 W. in Deuel County.

JAMES LOBE ALTAMONT MORAINE

The James Lobe Altamont moraine was named by Tipton and Steece (1965) for the outer moraine of the James Lobe ice in eastern South Dakota. Although Flint (1955) had correlated it with the

Bemis moraine, it is morphologically identical to the Altamont moraine on the eastern edge of the Coteau des Prairies. It is a hummocky complex of knobs, kettles, and disintegration ridges up to 5 miles wide trending northwest-southeast through central Hamlin County. It is poorly drained and contains many sloughs. The moraine surface has very little loess and is composed primarily of till with isolated ridges of silt, sand, and gravel. It is breached by a meltwater channel in T. 114 N., R. 52 W. and by Lake Poinsett and Dry Lake in T. 113 N., R. 52 W. The distal slope is in contact with outwash valley train deposits and stream dissected till plain to the east, and the proximal slope is in contact with stagnation moraine and collapsed outwash to the west.

Stagnation Moraine

Stagnation moraine covers more area on the Coteau des Prairies than any other landform, and includes the western half of Hamlin County and about one-fourth of Deuel County. Landforms found in stagnation moraine were formed primarily by glacial stagnation (Clayton, 1962) and ice disintegration (Gravenor and Kupsch, 1959). Stagnation moraine has also been called dead-ice moraine, disintegration moraine, hummocky disintegration moraine, hummocky moraine, collapsed moraine, collapsed drift, ablation moraine, stagnation drift, and ice-stagnation drift (Flint, 1955; Clayton, 1967; Hedges, 1972; and Steece, 1972).

Stagnation moraine was first recognized in South Dakota by Flint (1955) who called fields of smooth, circular depressions "collapsed drift." Hedges (1972) and Christensen (1974, 1977) recognized stagnation drift and stagnation moraine respectively on the north and south extremes of the Coteau du Missouri and Steece (1972) and Koch (1975) both discuss the presence of ice-stagnation drift and stagnation moraine on the Coteau des Prairies in South Dakota.

The term "stagnation moraine" as used in this report refers to a class of landforms formed by ice disintegration, whereas, "stagnation drift" refers to the material from which the landforms are constructed. Although the landform mapping units used on plate 1 are differentiated lithologically, they correspond to features formed as a result of glacial stagnation and subsequent ice disintegration. The following are descriptions of several different types of ice-disintegration landforms found in the two Counties.

STAGNATION MORAINE - TILL

The western half of Hamlin County is characterized by stagnation moraine composed primarily of till (pl. 1). The surface is generally smooth with many arcuate-shaped sloughs surrounding round to polygonal-shaped hills of till and silt. The average relief between hill tops and adjacent depressions is about 20 feet. There are no dominant transverse linear elements. The area closely resembles the field of closed disintegration ridges in a low relief till area described by Gravenor and Kupsch (1959, pl. 2) as an example of uncontrolled ice disintegration, the definition of which is as follows:

> When the forces that operate to break up an ice sheet are equal in all direction, the disintegration may be said to be uncontrolled, and the result is a field of round, oval, rudely hexagonal or polygonal features, and a general lack of dominant linear elements.

In some cases, the mounds of till or silt have depressions in the middle and resemble the rimmed kettles described by Parizek (1969). There is a possibility that the polygonal-shaped features are periglacial in origin, but further study must be done before the mechanics of deposition and deformation can be fully determined.

The stagnation moraine near Hayti, Hamlin County, consists of many circular disintegration ridges or "doughnuts." These features are relatively small (10 to 20 feet in diameter) and can only be seen in detail on aerial photographs.

In Deuel County, the stagnation moraine composed primarily of till ranges in local relief from 10 to 90 feet. Drainage is mostly internal, but several meltwater channels transect the area which contains streams that drain west to east off the Coteau des Prairies. The area is generally characterized by linearity both on a large and small scale. Stagnation moraine roughly parallels the Bemis and Altamont moraines throughout the length of the County. On a smaller scale, there are hundreds of linear and circular disintegration ridges.

A fairly continuous band of these linear disintegration ridges was mapped by Flint (1955) as the Gary moraine. The "moraine" is actually a series of crevasse fillings deposited during stagnation of the ice sheet. Features formed in this area are similar to those attributed by Gravenor and Kupsch (1959) to controlled ice disintegration, the definition of which is (Gravenor and Kupsch, 1959, p. 49):

> Where the ice separated along fractures or other lines of weakness, the disintegration may be said to be controlled, and the result is a field of linear or lobate land forms. In places the ice broke along open crevasses or along thrust planes, both of which formed when the ice was still flowing, and the disintegration thus shows inherited flow control. The linear elements then bear a direct and understandable relation-

ship to the preceding flow directions and are usually parallel, perpendicular or at 45 degrees to the direction of flow.

Crevasse fillings along the east edge of the stagnation moraine in contact with the colluvial slope of the Coteau des Prairies in Deuel County (pl. 1) are formed by material deposited in fractures perpendicular to the direction of ice flow. Thus, the stagnation moraine in Deuel County generally shows inherited flow control.

COLLAPSED OUTWASH

Much of the glaciofluvial sediment found in the two Counties was deposited on blocks or sheets of stagnant ice. The resulting landform is similar in appearance to stagnation moraine composed of till. In Hamlin County, collapsed outwash occurs between Lake Poinsett and Lake Norden and also in the Five Ponds area (pl. 1). In Deuel County, most of the collapsed outwash occurs in association with stagnation moraine found along the proximal slope of the Altamont moraine. In both Counties, the collapsed outwash contains ice-block basins which are now occupied by lakes.

A meltwater channel along the Deuel-Grant County border is partially filled with hills and ridges of outwash and has linear disintegration ridges along the valley wall. This area is similar in appearance to one in Saskatchewan described by Parizek (1969, p. 75) as ice-contact ridges adjacent to channels formerly occupied by stagnant ice.

COLLAPSED LAKE PLAIN

There are about 10 square miles of collapsed lake sediment in the Lake Norden area of Hamlin County (pl. 1). The sediment is composed of clay, silt, and fine sand up to 65 feet thick. This collapsed lake plain is bordered on all sides by collapsed outwash which is 30 to 50 feet higher in elevation than the lake plain. The surface of the lake plain is relatively smooth with a few ridges and knobs of fine sand and silt. Associated with the lake plain are several large kettle lakes formed by ice-block remnants of the stagnant late Wisconsin ice sheet.

Outwash Valley Train

A valley train is a long, narrow body of outwash that is confined to the channel in which it rests. The valley of the Big Sioux River contains this type of deposit. The river served as the only conduit for glacial meltwater in the area for a considerable portion of late Wisconsin time. Outwash material was transported to the valley by numerous outlet channels leading away from both the James Lobe and Des Moines Lobe ice. The deposit is up to 30 feet thick in many places along the valley.

Outwash Terraces

Terraces of glaciofluvial material occur along the Big Sioux River and Hidewood and Stray Horse Creeks. The most prominent terrace, near Estelline, Hamlin County, stands about 75 feet above the floor of the Big Sioux River Valley and is composed of very fine sand to coarse, bouldery gravel. This terrace is 3 miles in length and is bordered by Bullhead Run on the north and Peg Munky Run on the south. Outwash on the terrace is at least 37 feet thick but coarse gravel prevented deeper drilling. The terrace is a remnant of a glaciofluvial flood plain. Terraces found along Hidewood and Stray Horse Creeks are up to 50 feet above their respective flood plains and are associated with the formation of the Bemis moraine.

Lower terrace levels found along the Big Sioux River Valley exist up to 20 feet above the present flood plain and contain more silt and clay than does the outwash in the valley train. Contact between the terrace and valley floor is subdued and masked in places by colluvial deposits.

Meltwater Channels

There are many channels present in Deuel and Hamlin Counties that were formed as drainage outlets for glacial meltwater. The channels west of the Big Sioux River in Hamlin County and east of the Altamont moraine in Deuel County are associated with stagnation moraine. These channels are relatively short (1 to 3 miles in length) and narrow (1/8 mile wide) and generally contain little outwash.

Large meltwater channels (along Hidewood and Stray Horse Creeks; and Bullhead and Peg Munky Runs) are parallel to the major direction of former ice flow and transect the Bemis moraine and the loess covered till plain. These channels impart up to 150 feet of local relief and range from 1/8 to 1-1/2 miles in width. Tributary to the main channels are numerous ice-marginal channels, particularly along the distal slope of the Bemis moraine. The main channels contain up to 60 feet of outwash, but the tributary channels contain mostly recent alluvial and colluvial deposits.

Several hillside channels were formed by melting stagnant ice on the proximal slope of the Bemis moraine in T. 113 N., R. 48 W., Deuel County (pl. 1). These channels are less than 1/8 mile wide and 1/4 to 1 mile in length. They contain little fluvial sediment and are open at both ends, conforming to the definition of hillside channels given by Flint (1971, p. 230).

Lake Plains

There are several glacial lake plains in Hamlin County ranging from 1/4 to 4 square miles in area. All are located west of the Poinsett moraine and occur within stagnation moraine. Glacial lake silts and clays contained within these lake plains are up to 70 feet thick. The lake beds themselves are about 40 feet below the surrounding moraine and 25 feet above present-day lake levels. These lake basins were formed by melting blocks of glacial ice, as were the basins presently occupied by Lakes Poinsett, Five Ponds, and Marsh.

In Deuel County, about 20 square miles of glaciofluvial and lacustrine sediment were mapped between the Bemis and Altamont moraines. The area is relatively flat and had been previously mapped as ground moraine by Flint (1955). In this area lake beds and outwash beds are 20 to 40 feet below the surrounding moraine surface. Several knobs and ridges of gravel up to 29 feet high rise above the lake bed. All of the major lake basins in Deuel County were formed by melting blocks of ice.

In the extreme northeast corner of Deuel County is another area of lacustrine deposits. These sediments are believed to have been deposited in a lake (or lakes) that formed as meltwater was ponded between the glacial ice in the Minnesota River Valley and the Coteau des Prairies.

Nonglacial Landforms

Physical and chemical processes have not significantly altered the landscape since the glaciers retreated. However, modification of the landscape in post-glacial time has produced a few landforms that are large enough to be considered separately.

Coteau Slope

The eastern escarpment of the Coteau des Prairies in Deuel County is covered with colluvial deposits. This material was originally deposited as glacial drift on higher portions of the slope, but has been moved downslope by a variety of processes. It commonly shows a weakly developed stratification parallel to the land surface. The colluvium forms an "apron" covering about 15 square miles in the northeastern portion of the County (pl. 1). The Coteau slope is cut by several stream channels. The contact between the Coteau slope and the morainic topography to the west is marked by an abrupt increase in slope and the presence of linear disintegration ridges. To the east, the Coteau slope is in contact with a former glacial lake bed composed of clay and silty clay.

Recent Stream Channels

All of the major streams in Deuel and Hamlin Counties flow in former meltwater channels formed when the volume of water passing through them was many times greater than today. These streams are now considered underfit, that is, their present discharges are too small to account for the erosion of the valleys they occupy (Drury, 1968).

Tributaries to the major streams, other than ice-marginal channels, have all formed through headward erosion. This continuing process of erosion provides sediment that is deposited as recent alluvium.

Sloughs

Most potholes or sloughs in the two Counties occupy basins formed by melted blocks of glacial ice. Slumping and slope wash since glaciation has partially filled the basins and reduced side slopes. Wave action has eroded banks and steepened slopes in the basins that contain lakes or open water.

GEOMORPHIC DEVELOPMENT

Pre-Pleistocene Drainage and Topography

The land surface of Deuel and Hamlin Counties prior to the Pleistocene Epoch was characterized by drainage developed on Cretaceous shales and marls. Drainage patterns were most likely similar to those now present in the "Pierre Hills" area of west-central South Dakota. Test drilling did not supply enough data to map the buried surface in detail, but the general distribution of bedrock highs and lows was determined. Figure 3 shows the general topography of the bedrock surface underlying the glacial drift. Although this map represents the bedrock surface after glacial modification, the general configuration is probably the same.

The bedrock surface in the two Counties slopes from west to east at about 7 feet per mile. It is cut by two broad valleys, which are up to several hundred feet lower than the surrounding areas. One channel cuts across Hamlin County from northwest to southeast and the other is located in northeastern Deuel County (fig. 3).

The configuration of the bedrock surface would have had an effect on the movement of the earliest glaciers that moved into this area. However, its influence would have diminished as each successive ice advance added to the accumulation of glacial drift.

Drift Complex I

The distribution of Drift Complex I is shown on the cross sections (pl. 2) and in figure 4. This drift unit represents many advances and retreats of early Pleistocene glaciers, but there were insufficient data available to the writers to separate the material according to specific episodes of glaciation. Basal outwash associated with the Drift Complex I unit and found on top of bedrock is presumed to be proglacial in origin. As the first ice sheet advanced, it blocked preexisting drainages and modified the topography by filling in low areas with drift. For the most part, the high and low areas on the Drift Complex I surface correspond to those on the bedrock topographic map. A bedrock channel in west-central Hamlin County is reflected on the Drift Complex I surface. The trend of this channel continues across southern Deuel County and may represent a broad marginal position of earliest Pleistocene ice (fig. 4). The high area on the Drift Complex I surface in southwest Deuel County is just south of the east-west channel and represents an accumulation of up to 350 feet of glacial drift. A low trough trending north-south through eastern Hamlin County is bordered by two ridges on the drift surface.

Material associated with Drift Complex I has been removed by subsequent glaciation in northeastern Deuel County. A line marking the limit of the occurrence of Drift Complex I in this area roughly parallels the Coteau des Prairies escarpment. In southwestern Hamlin County, no evidence of Drift Complex I was found. Some of the outwash silts and sand found in the bedrock lows in this area were derived from Drift Complex I material, but erosion and deposition of the sediment were caused by glaciation associated with Drift Complex II.

Drift Complex II

Drift Complex II is separated from Drift Complex I in most places by a buried oxidized zone (pl. 2). The surface of Drift Complex I afforded topographic control of the ice flow direction and subsequent distribution of Drift Complex II (fig. 5). The topographic surface of both buried drift sheets generally conform, but there are several exceptions. In western Hamlin County, a broad sag or channel in the Drift Complex II surface is oriented north-south, whereas, on the Drift Complex I surface the sag is oriented northwest-southeast. Also, the broad valley in the buried Drift Complex I surface beneath the Big Sioux River Valley becomes more pronounced on the Drift Complex II surface.

There is a prominent topographic high on the Drift Complex II surface that crosses central Hamlin County (fig. 5). The oxidized drift zone beneath this ridge is relatively thick (pl. 2). This feature is believed to mark the limit of the first late Wisconsin advance.

Positions of the channels in the Drift Complex II surface correspond closely to that of the buried bedrock channels postulated by Flint (1955). These buried channels are expressed at the land surface by meltwater channels and kettle chains in the late Wisconsin drift. Thus, the distribution of the surface drift was primarily controlled by the paleotopography of the Drift Complex II surface and not directly by the bedrock.

Drift Complex II is absent in northeast Deuel County due to erosion by late Wisconsin ice and meltwaters.

Drift Complex III

In this report, the general theory upon which the glacial history is based is that there was only one major glaciation during late Wisconsin time. All surface deposits and landforms evident within the study area originated at this time. For mapping purposes, and to avoid introducing additional names to an already cluttered nomenclature, the two subdivisions of this time span are designated numerically (late Wisconsin I and late Wisconsin II). The basic difference between the two units is that late Wisconsin II deposits still exhibit constructional topography, while late Wisconsin I features have been altered by erosion.

Earlier work in the area has produced a variety of classification schemes for the surface deposits (fig. 7). Flint's comprehensive work (1955) used a four-part Wisconsin system developed in the Great Lakes region. Subsequent work has recognized the difficulty in such long range correlation, and has tended to produce more elementary divisions of the glacial history. The late Wisconsin I deposits in this area was mapped as Iowan and Tazewell by Flint (1955), Iowan by Steece (1957a, b, c,), and early Wisconsin by Tipton and Steece (1965). Late Wisconsin II deposits were mapped as Cary and Mankato by Flint (1955), Tazewell and Cary by Steece (1957a, b, c) and Tipton (1958) and late Wisconsin by Tipton and Steece (1965). In the following discussion of the late Wisconsin deposits, a number of points used either by the authors or earlier investigators will be examined to establish the age of the surface deposits.

Late Wisconsin I

The first late Wisconsin ice overrode the Coteau des Prairies from the northeast, covering all of Deuel County and the eastern half of Hamlin County about 23,000 rybp. This time estimate is based on a radiocarbon date of 22,900±1,000 rybp (GX-3439) for wood recovered from lacustrine sediments found above Drift Complex II in a test hole in Hamlin County (fig. 6). This date gives a maximum age for Drift Complex III and correlates well with other late Wisconsin chronologies in the midcontinent region (table 2). The test hole was drilled on the till plain mapped as

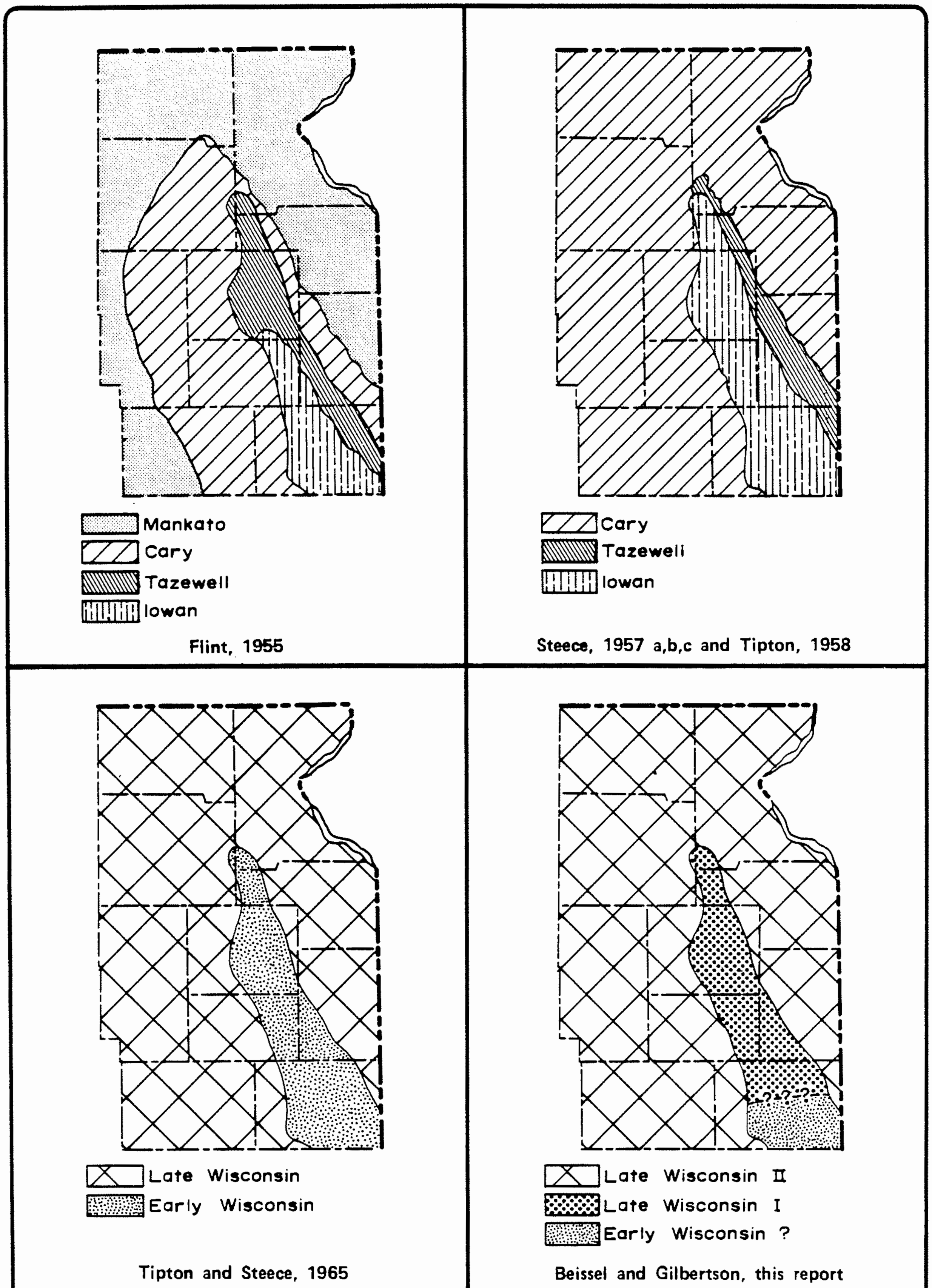
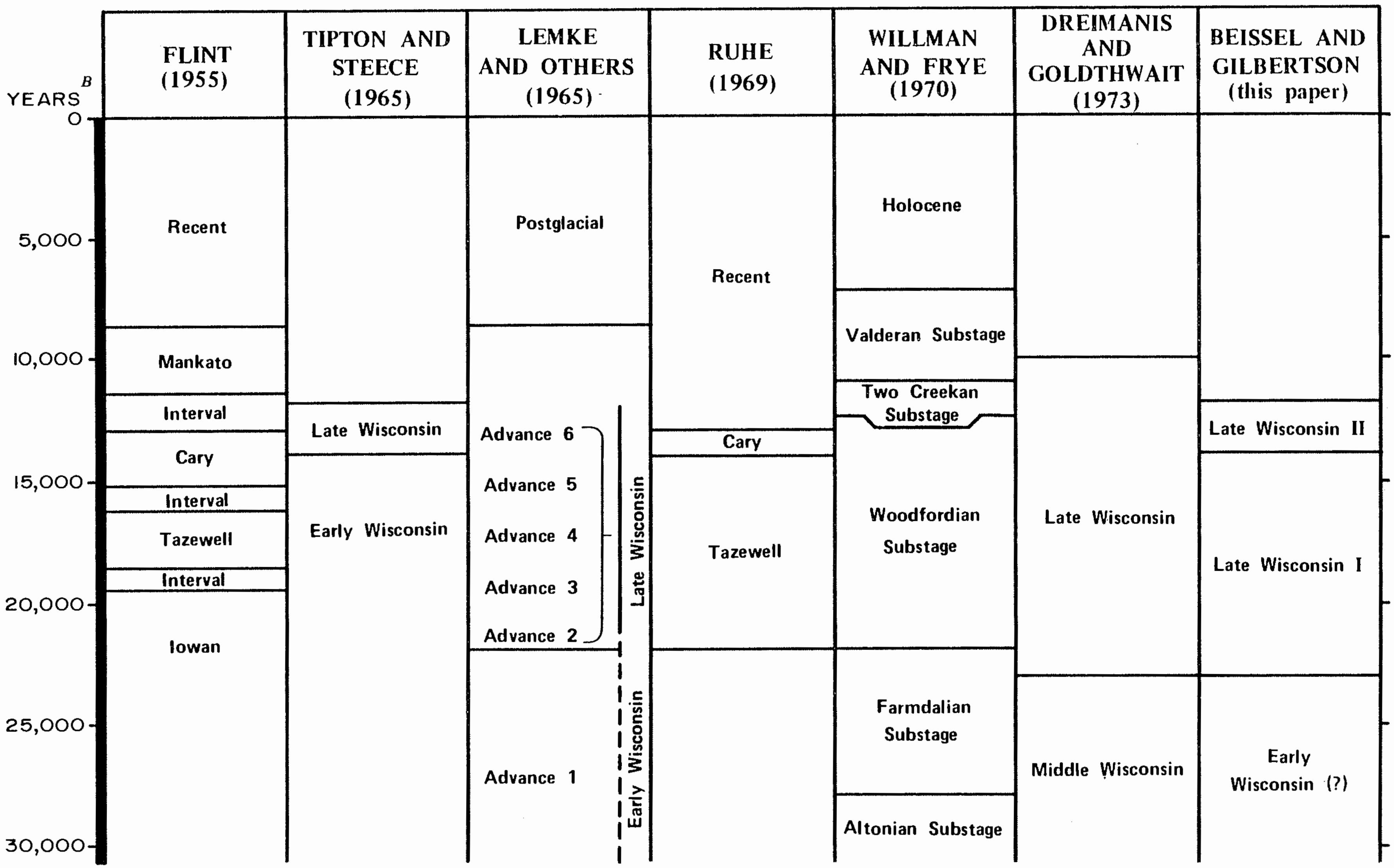


Figure 7. Classification systems used to describe the surficial geology of northeastern South Dakota. Refer to figure I for county names.

Table 2. Classification and correlation of Wisconsin glaciations in the Midwestern and North-Central United States.[A]

[A] *Modified from Lemke and others (1965) and Dreimanis and Goldthwait (1973).*

[B] *Time scale in radiocarbon years before present.*



either Iowan or early Wisconsin by earlier writers (fig. 7). Two private wells drilled in the general area have produced wood from what is believed to be about the same stratigraphic interval. Wood from a 90-foot well in Hamlin County was dated at 26,150±3,000 rybp (GX-2864) and a 140-foot well in Brookings County has been dated at greater than 30,000 rybp. However, because there is a considerable amount of uncertainty as to the exact source of the wood, these dates have not been used in this report. 1

Late Wisconsin I surface deposits in Deuel and Hamlin Counties are mapped as stream dissected till plain, Qwlt1, on plate 1. The well integrated drainage network developed on this surface (fig. 2) and the presence of loess on the till surface has been sited in previous works (Tipton and Steece, 1965, for example) as indicating an older than late Wisconsin age. However, this drift surface is transected by several major drainage channels, as well as the Big Sioux River. No point on the till plain is more than 3 miles from one of these channels. They have provided the local base level from at least the time of the formation of the Bemis moraine, and probably earlier. It is not unreasonable to assume that a well integrated stream network could develop in this area, given the close proximity of such channels. The drainage network that has developed on the Bemis and James Lobe Altamont moraines and younger deposits is poorly integrated, which is more typical of late Wisconsin age surfaces. Drainage development on these surfaces, without the benefit of the drainage channels, has progressed much more slowly.

The late Wisconsin I drift surface is covered with a thin layer of loess, which has been cited as an indication of a pre-late Wisconsin age. No loess is found on the Bemis moraine, which marks the eastern limit of the surface. However, a close examination of the distribution of the loess shows that the deposit thins rapidly as one moves away from the Big Sioux River, from a maximum thickness of 5 feet to less than 1 foot near the Bemis moraine. It would appear that the reason the Bemis moraine is not mantled with loess is its distance from the Big Sioux River, not its age.

Aside from the radiocarbon date, there is other stratigraphic evidence to support the late Wisconsin age of the till plain. Drilling in the study area frequently encountered one or two buried oxidized zones, which represent older, pre-late Wisconsin surfaces (pl. 2). These oxidation zones, as well as lithologic

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[1] Further drilling, conducted for county-study investigations in Brookings and Codington Counties, indicates that the two questionable wood dates are also from the base of Drift Complex III. Because this information was not available at the time this report was first compiled, 1977, it was not included in this publication. How this additional information affects the interpretation of the regional geology will be addressed in later publications.

differences, are used to separate the three drift complexes discussed in this report. If the area mapped as late Wisconsin I in this report was significantly older than the late Wisconsin II deposits, one might expect to find a buried oxidized zone or other stratigraphic break separating these units. This would indicate that the major moraines mark the extent of a readvance of ice into the area after a long hiatus. However, no such zone was encountered, and no reasonable connection can be made between the till plain surface (late Wisconsin I) and the first buried zone (the top of Drift Complex II). While it is arguable that evidence of the "missing" contact was eroded during the construction of the Bemis, Altamont, and James Lobe Altamont moraines, the failure to encounter any break suggests that it did not exist at all.

Drift Complex III deposits thin markedly in the area of the Big Sioux River and the James Lobe Altamont moraine (pl. 2). It is speculated that the first ice advance moved into the area from the northeast and extended as far as central Hamlin County. At this point the ice encountered a prominent ridge of Drift Complex II material. The Big Sioux River may have been formed at this time as an ice-marginal drainage, trapped between the glacial ice and the Drift Complex II ridge. Drift Complex III sediments that cover western Hamlin County and the James Lobe Altamont moraine were deposited during subsequent glacial activity.

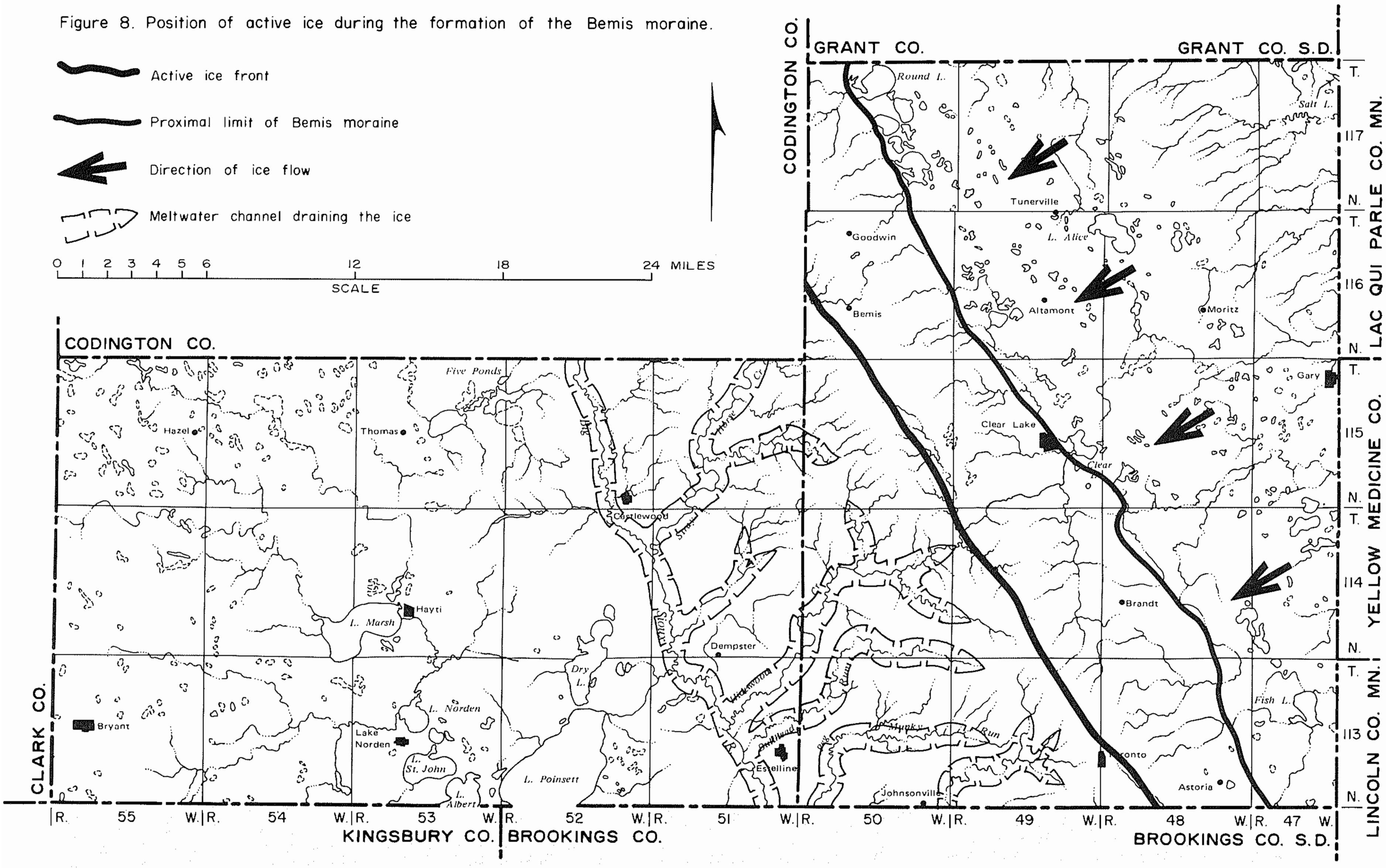
The extent of coverage of this first phase of late Wisconsin glaciation in eastern South Dakota is uncertain. There is a compositional change in the surface till to the south in Brookings County (Tipton, personal communication, 1978), but a topographic break is absent. Any morainic features that may have formed as result of late Wisconsin I ice have been destroyed by erosion or buried by subsequent advances.

Late Wisconsin II

About 14,000 rybp, glacial ice returned to the study area. There were then two lobes of glacial ice along the flanks of the Coteau des Prairies. The Des Moines Lobe was to the east and the James Lobe was to the west. The Des Moines Lobe ice reached equilibrium at the Bemis moraine position (fig. 8). While no radiocarbon dates exist for the Bemis moraine in South Dakota, numerous dates ranging between 13,775 and 14,700 rybp have been generated in Iowa (Ruhe, 1969, table 2.7). The position of the James Lobe ice front at this time is uncertain, as there is no "James Lobe" Bemis moraine evident west of the Big Sioux River. If such a moraine was formed, it has been completely covered by later deposits.

Drainage from the ice at the Bemis moraine position was down Willow, Hidewood, Stray Horse, and Deer Creeks (fig. 8). Peg Munky Run, Bullhead Run, North Deer Creek, and other small tributary channels were formed as ice-marginal channels along the

Figure 8. Position of active ice during the formation of the Bemis moraine.



receding ice front before it reached the Bemis moraine position. High-level terrace remnants found along these drainages are from this time period.

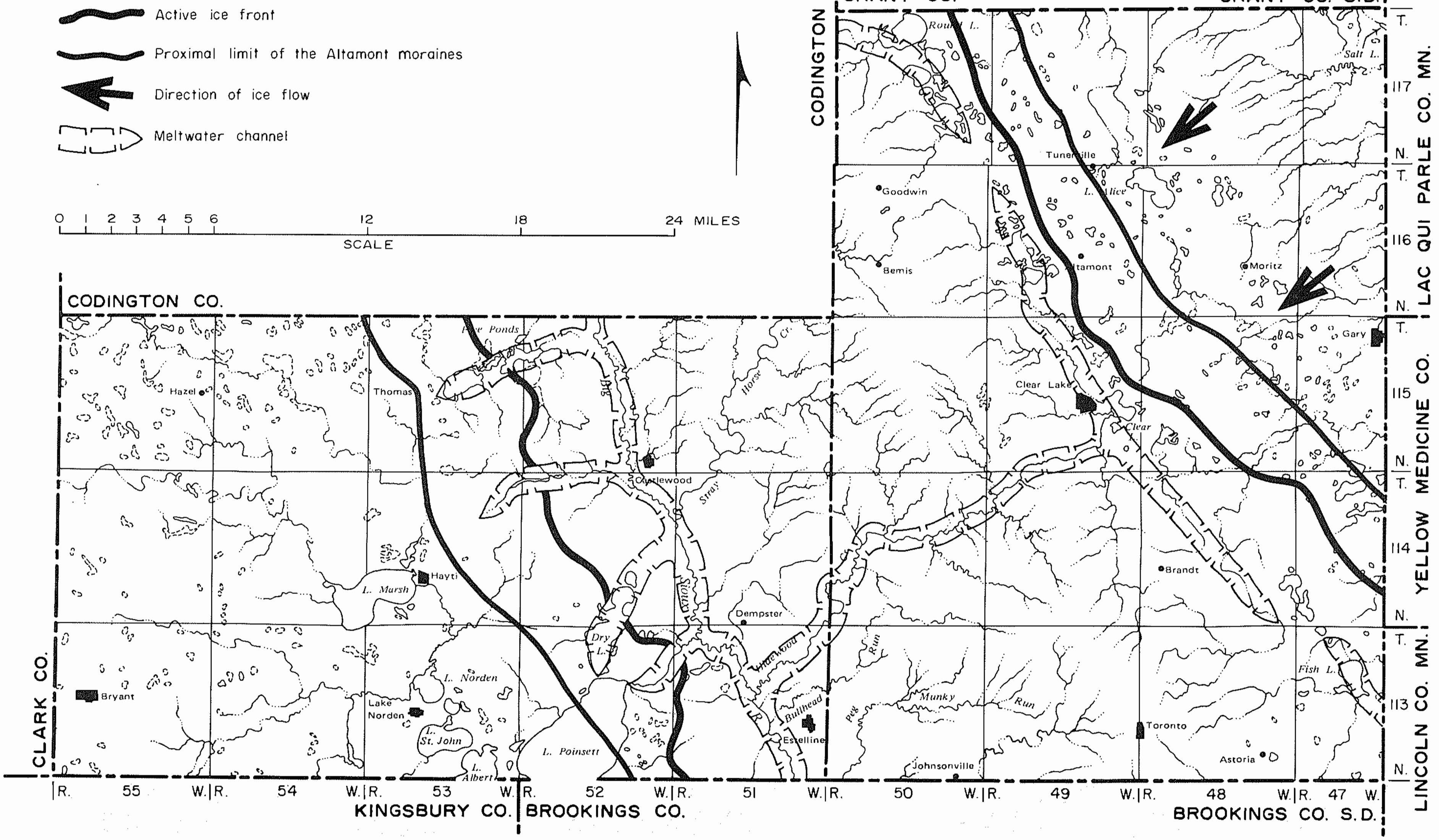
By about 13,000 rybp (Ruhe, 1969) both lobes had again stabilized, forming the Altamont moraine in central Deuel County and the James Lobe Altamont moraine in central Hamlin County (fig. 9). These two moraines coalesce in eastern Day County, about 45 miles north of the study area. Meltwater from the ice forming the James Lobe Altamont moraine flowed directly into the Big Sioux River, but water from the ice forming the Altamont moraine was ponded behind the Bemis moraine. This intermorainic area (Antelope Valley) was filled with up to 100 feet of glacial outwash and today is a major local aquifer (Kume, 1985). Eventually the Bemis moraine was breached and meltwater flowed into the Big Sioux River along Willow, Hidewood, Stray Horse, and Deer Creeks (fig. 9).

Eventually, flow in the two ice lobes diminished to the point where they could no longer support active ice on the Coteau des Prairies. When active ice was restricted to adjacent lowlands, much of the Coteau des Prairies surface was left covered with sheets and blocks of stagnant ice. As the ice melted, the variety of stagnation features described earlier were formed. It is believed that the ice west of the James Lobe Altamont moraine was relatively "clean" because of the low amount of local relief. The dead ice east of the Altamont moraine apparently contained a considerable amount of glacial sediments because the local relief is quite pronounced.

Meltwater from the ice adjacent to the Big Sioux River Valley or the edge of the Coteau des Prairies was carried away in established or developing drainages. However, in the central portions of the stagnant ice, meltwater did not always have a ready exit. Some of the water flowed over the unmelted portions of the ice. Today these drainages are marked by collapsed outwash plains, such as those adjacent to Lakes Marsh and Poinsett. In many cases no stream network has yet developed, and most of the stagnation drift areas today have only internal drainage. This has resulted in the formation of extremely saline lakes as minerals dissolved by runoff are concentrated by evaporation in the lake basins. Analysis of water from Nicholson Lake in Codington County, north of the study area, has shown that in the late summer mineral concentrations have reached nearly 200,000 parts per million (Tipton and others, 1972, p. 106). Sea water typically contains about 35,000 parts per million.

A series of parallel disintegration ridges are present along the contact between the colluvial slope and stagnation moraine in Deuel County (pl. 1). They represent crevasse fillings deposited in fractures in the ice caused by flexure of the ice sheet along the "hinge line" of the underlying Coteau des Prairies slope. These ridges are previously mapped as part of the Gary end moraine by Flint (1955).

Figure. 9. Position of active ice during the formation of the Altamont and James Lobe Altamont moraines.



Most of the extreme northeastern portion of Deuel County is covered with lake sediments. Meltwater flowing off the edge of the Coteau des Prairies was either ponded against the Des Moines Lobe ice or water from the Des Moines Lobe ponded against the Coteau des Prairies. A number of small, esker-like ridges cross this area at right angles to the slope of the Coteau des Prairies. They stand from 5 to 10 feet above the local land surface and are composed of sand and gravel. They may also have originated as fracture fillings like those found on the Coteau des Prairies.

Holocene

After the last stagnant ice melted, erosion and deposition in Deuel and Hamlin Counties was caused mainly by local precipitation and runoff. Mudslides, creep, and deposition of eolian sediment also occurred, but mapping of hillslopes, slough deposits, and loess was not included in this study. A good discussion of recent or post glacial geologic processes can be found in Ruhe (1969).

ECONOMIC GEOLOGY

Water

Ground and surface water are the most important natural resources in Deuel and Hamlin Counties. Without the availability of water, productive agricultural, industrial, recreational, and domestic use of the land would be impossible. Because of drought conditions in the mid-1970's and the prospect of future droughts, the use of ground water for irrigation and public work supplies is increasing. The geologic information in Part I and hydrologic data in Part II of this report can be used as a starting point for future planning of natural-resource development. However, further hydrologic study is needed in eastern South Dakota before efficient and wise use is made of the water resources.

Part II: Water Resources of Deuel and Hamlin Counties, South Dakota (Kume, 1985), and South Dakota Geological Survey Information Pamphlet No. 11, (Kume, 1976) contain surface- and ground-water information collected during this study. Information Pamphlet 11 provides maps and general descriptions of the major aquifers in the two Counties.

Sand and Gravel

Sand and gravel, an important resource used chiefly to maintain county and townships roads, is relatively abundant in Deuel and Hamlin Counties. South Dakota Geological Survey Information Pamphlets 9 and 10 (Schroeder, 1976a, b) contain the sand and gravel data collected during the study. Maps in these reports which are available from the County Auditors show active and inactive gravel pits, test-hole locations, and the probability of finding additional sand and gravel in selected areas.

Clays

All of the clay deposits found in the study area were derived from glacial material. They are silty and contain too much carbonate for commercial use.

Oil and Gas

There are no oil and gas wells in Deuel and Hamlin Counties and no known reserves. Recent work with oil shale in the State indicates the possibility of future reserves in eastern South Dakota, but the thickness of glacial drift in Deuel and Hamlin Counties will probably remove them from consideration for development.

RECOMMENDATIONS FOR FURTHER STUDY

Any investigative scientific report, no matter how general or comprehensive, should inspire new study. There are several general geologic and hydrologic studies which could be done; some strictly academic, others necessary and immediately practical.

1. A comprehensive sampling and statistical analysis program on the tills in eastern South Dakota should be initiated. Several preliminary studies have started, but they have not been coordinated on either an intra- or interstate basis. A coring program accompanying this study would be desirable.

2. A loess thickness and mineralogy study on the Coteau des Prairies accompanied by a coring program directed to slough or lake deposits would help reconstruct paleoclimates. Pollen analysis and paleontological work similar to the Pickerel Lake Study (Wright, 1972) could be included.

3. Although drilling costs may be prohibitive, more work is needed on the bedrock stratigraphy in eastern South Dakota. The few stratigraphic tests available are useful, but not adequate to regionally define stratigraphic units.

4. Future hydrologic studies should include aquifer-test analyses and digital modeling. This could be done economically only for the major aquifers. It would be important not to limit hydrologic study to political boundaries. Perhaps it would be best to redefine study

areas, e.g., at least use watershed boundaries or drainage basins. This could be considered after the county-geologic studies are completed.

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