North Dakota Geological Survey
WILSON M. LAIRD, *State Geologist*
BULLETIN 43

North Dakota State Water Commission
MILO W. HOISVEEN, *State Engineer*
COUNTY GROUND WATER STUDIES 4

GEOLOGY AND GROUND WATER RESOURCES

BARNES COUNTY, NORTH DAKOTA

PART I

GEOLOGY

By
T. E. Kelly
Geological Survey
United States Department of the Interior
and
D. A. Block
North Dakota Geological Survey

Prepared by the United States Geological Survey in cooperation
with the North Dakota State Water Commission,
North Dakota Geological Survey,
and Barnes County Board of Commissioners
— 1967 —

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This is one of a series of county reports published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Commission. The reports are in three parts; Part I describes the geology, Part II presents ground water basic data, and Part III describes the ground water resources.

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GEOLOGY AND GROUND WATER RESOURCES of Barnes County, North Dakota

Part I - Geology

by T. E. Kelly and D. A. Block

ABSTRACT

Barnes County, in southeastern North Dakota, has an area of approximately 1,500 square miles. The physiographic features are the result of glaciation. Most of the county is characterized by gently undulating plains of ground moraine separated by relatively narrow, elongate end moraines. Although most of the area lacks an integrated drainage system, the deeply entrenched Sheyenne River traverses the county from north to south. The Continental Divide, which separates the Gulf of Mexico and Hudson Bay drainages, crosses the western part of Barnes County.

Rocks of Cambrian and Ordovician age are separated from Cretaceous strata by an angular unconformity. The Cretaceous rocks are subdivided into the Dakota Group, the Colorado Group, and the lowest formation of the Montana Group. These units dip westward into the Williston Basin. In Barnes County, the total thickness of these consolidated rocks is about 2,400 feet.

The bedrock surface, which was eroded on shales of the Colorado and Montana Groups, generally slopes from west to east at about 15 feet per mile. The Spiritwood channel, a major southward-trending bedrock channel, was eroded more than 250 feet deep prior to glaciation. This channel and its tributaries underlie much of western Barnes County and adjacent Stutsman County.

The landforms and drainage systems of the county were formed during the late part of the Wisconsin glaciation. At least seven distinct drifts are present in Barnes County. These were differentiated mainly on the basis of landform rather than lithology. The Millarton, Eldridge, Buchanan, and Cooperstown drift sheets were all formed at the margin of a receding ice mass, whereas the Kensal-Oakes and Luverne drifts are associated with significant readvances of the ice mass.

An additional drift unit, the Sheyenne Valley drift, is exposed in the valley of the Sheyenne River, but its relative age and areal distribution are problematical.

Lake Lanona was ponded when the Luverne ice mass blocked the Sheyenne River. This proglacial lake had an area of about 160 square miles, and inundated most of central Barnes County.

Bald Hill Creek and the ancestral Sheyenne River originated as meltwater channels during the Cooperstown phase of glaciation, but the present headwaters of the Sheyenne were not established until Luverne time. Throughout much of its early history, the Sheyenne River emptied into the James River. Following ice withdrawal from Barnes County, but prior to Lake Agassiz, it drained into the Minnesota River via an ice marginal channel called the Milnor channel. Its present course east of Lisbon was established while Lake Agassiz was in existence and, also, subsequent to drainage of the lake.

INTRODUCTION

Location and Purpose

Barnes County, which is located in southeastern North Dakota, has an area of approximately 1,500 square miles (fig. 1).

The geology of the county was studied as part of a cooperative investigation of the ground-water resources by the U.S. Geological Survey, North Dakota State Water Commission, North Dakota Geological Survey, and Barnes County Board of Commissioners.

The glacial deposits are the principal sources of ground water in the county, whereas the older rocks are secondary sources. Thus, the major objectives of this report are to summarize the geology of the pre-Quaternary rocks and to give a detailed description of the character and occurrence of the glacial drift within the county. The report also contributes to a better understanding of the glacial history of the area.

Fieldwork

Fieldwork for this study was done by D. A. Block, North Dakota Geological Survey, and Q. F. Paulson and the writer, U. S. Geological Survey. Block mapped 24 townships in the northern part of the county. The southernmost 18 townships in Barnes County were mapped by Paulson and the writer. The work done by Block was submitted to the Department of Geology, University of North Dakota, in partial fulfillment of the requirements for a Ph.D. degree. The geologic map prepared by Block was made available to the writer; however, slight modifications were necessary in order to adapt the map units to those used in this report. The classification and nomenclature of the rock units conform to the usage of the North Dakota Geological Survey (Carlson and Anderson, 1965, fig. 3).

The mapping was done on aerial photographs at a scale of 1:20,000. This information was later transferred to 1:63,500 planimetric maps. U.S. Geological Survey topographic quadrangle maps at a scale of 1:24,000 were released for part of the county after the fieldwork was completed and were used in the final compilation of the geologic data.

Wells and test holes used in the report are numbered according to the system of the U.S. Bureau of Land Management (fig. 2). The first numeral indicates the township, the second the range, and the third the section in which the well or test hole is located. The letters following the section number locate the well within the section and are assigned in a counterclockwise direction, beginning with (a)

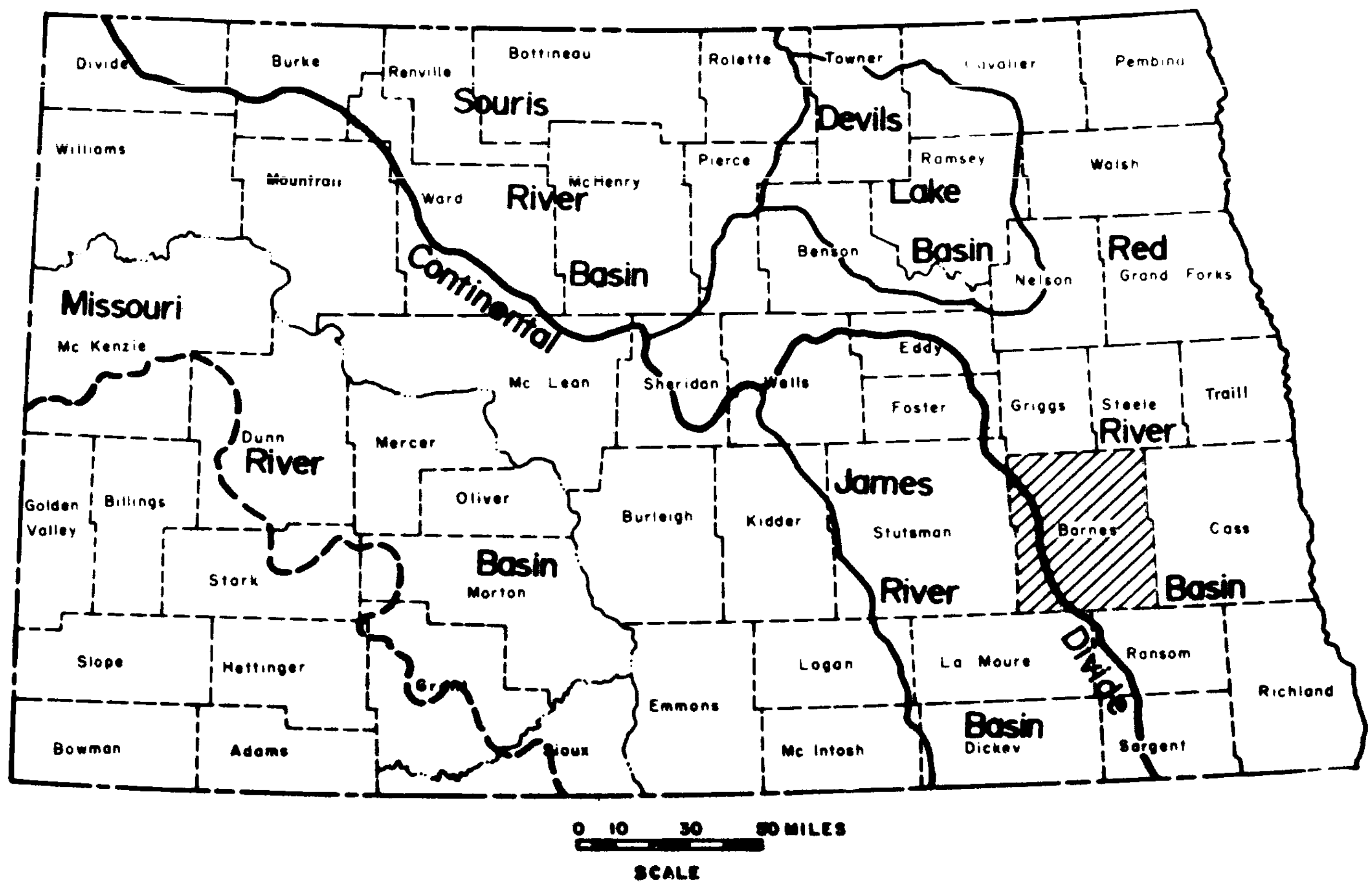

Figure 1. Location of Barnes County in relation to drainage basins and Continental Divide. (Modified after Inter-Agency Committee on Water Resources Subcommittee on Hydrology, 1961).

in the northeast quarter. The first letter denotes the quarter section, the second the quarter-quarter section, and the third letter the quarter-quarter-quarter section (10-acre tract). For example, well 138-57-15daa is located in the NE1/4-NE1/4SE1/4 of sec. 15, T. 138 N., R. 57 W. Consecutive numbers are added to the letters if more than one well is recorded within a 10-acre tract.

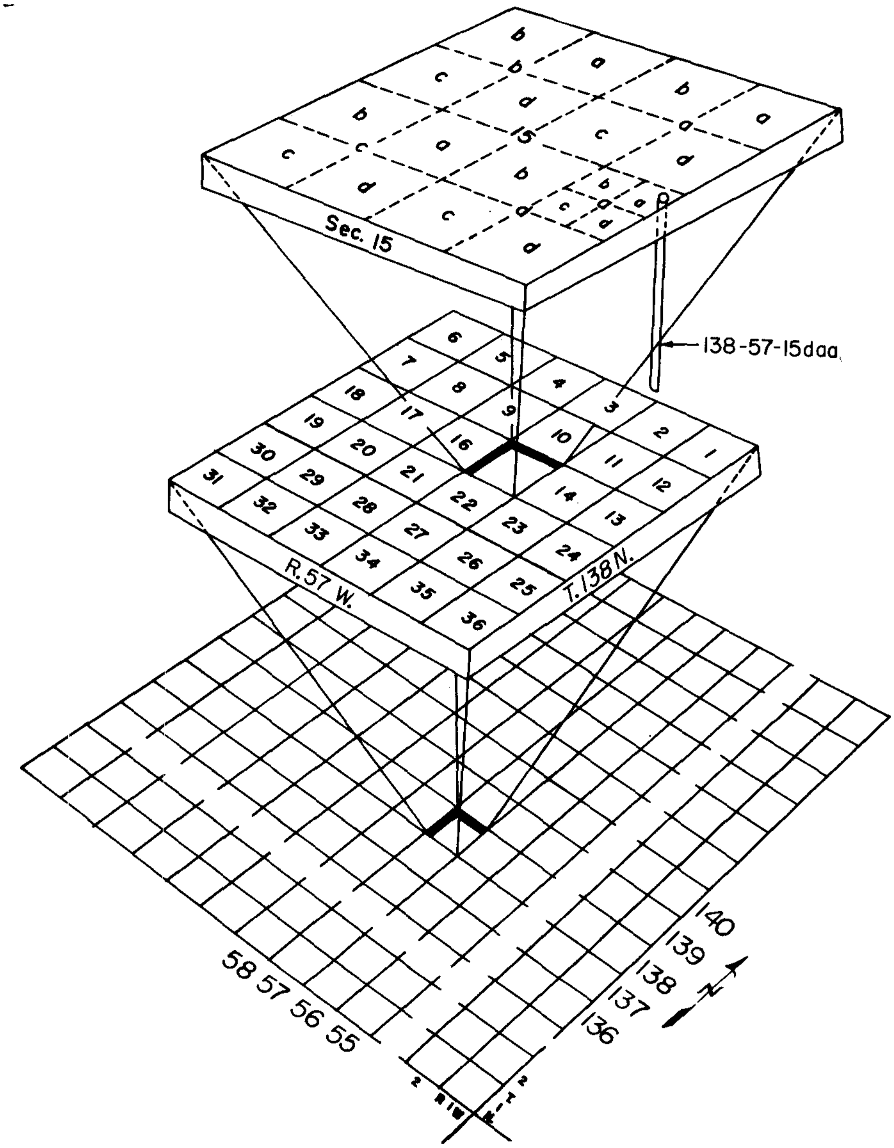

Figure 2. System of numbering wells and test holes.

Previous Investigations

The major glacial features within Barnes County were first described by Upham (1895) as part of a detailed study of glacial Lake Agassiz. The southern part of Barnes County and adjoining areas were studied by D. E. Willard (1909). Leverett (1912, 1932) made brief mention of the geology of the area as part of his studies in southeastern North Dakota. The first detailed study of the geologic deposits in Barnes County was made by Hard and Holmes (1912). This study was concerned primarily with soil types, and the origin and history of the soils were not described. Simpson (1929, p. 65-70) gave a brief description of the geology of the area as part of a statewide survey. A small part of northwestern Barnes County and adjacent Stutsman County was mapped and described by Dennis (1948). Akin (1952) described the geology of a part of southern Barnes County. Strassberg (1954) and Nelson (1955) described the stratigraphy at the sites of two oil tests in the county. Laird and Hansen (1957) prepared a geologic guidebook for central Barnes County. The most significant contribution to the geochronology of the area was made by Lemke and Colton (1958, p. 41-57) in their description of the Pleistocene history of the State. Huxel (1961a, p. 3-7) described the geohydrology of an area in central Barnes County and the subsurface geology of western Barnes and adjacent Stutsman County (Huxel, 1961b, p. 179-181). Colton, Lemke, and Lindvall (1963) prepared a map of the glacial geology of North Dakota. Kelly (1964a, p. 161-165) discussed the geohydrology of western Barnes County and eastern Stutsman County and described logs of test holes and other basic data (Kelly, 1964b).

Geologic studies made in surrounding areas also were used during the Barnes County study. Studies, pertinent to Barnes County, were made by Todd (1896, p. 13-59), Clayton (1962), Winters (1963), Bluemle (1965), Klausing (oral communication), and Baker (oral communication).

Acknowledgments

The writer wishes to express appreciation to his many colleagues; without their help the compilation of this report would not have been possible. Q. F. Paulson, U. S. Geological Survey, deserves special mention for his valuable professional criticism, and Wilson M. Laird, State Geologist, North Dakota Geological Survey, gave administrative assistance.

GEOGRAPHY

The dominant physiographic features of Barnes County are the elongate belts of end moraine and the deep valley occupied by the Sheyenne River (pl. 1, in pocket). In general, these features are separated by broad, undulating plains of ground moraine. Most of the county does not have an integrated drainage system.

Practically the entire area is mantled with glacial drift. The uplands are covered with till and associated glaciofluvial deposits, but bedrock is exposed in the valleys of the Sheyenne River and Bald Hill Creek. The flood plains of these streams are blanketed by alluvium. The arcuate Kensal-Oakes end moraine enters northwestern Barnes County near Wimbledon and extends more or less southeastward across the county and into adjacent Ransom County. The Luverne end moraine traverses from north to south, east of the Sheyenne River in Barnes County. Two smaller belts of end moraine, the Cooperstown and Eldridge, are present in the north-central and south-central parts of the county, respectively.

Total relief in Barnes County does not exceed 500 feet. The lowest point, approximately 1,080 feet, is on the flood plain of the Sheyenne River south of Kathryn. The highest point is 1,570 feet on the crest of the Luverne end moraine north of Valley City.

In general, the land surface slopes toward the Sheyenne River, with the exception of the area east of the Luverne end moraine that is drained by the Maple River on the east. The Sheyenne River flows southward through the central part of the county. The valley, which is about 2 miles wide and 150 feet deep, parallels the Luverne end moraine and separates it from other morainic belts to the west. A Continental Divide separating the Hudson Bay and the Gulf of Mexico drainage systems crosses the western part of the area (fig. 1). That portion of the county east of the divide is drained by the Red River of the North, which empties into Hudson Bay. West of the divide, the streams drain into the James River, which enters the Missouri River in South Dakota. Throughout much of central North Dakota, the Continental Divide coincides with the axis of the Kensal-Oakes end moraine or its equivalents. The axis of this end moraine and the Continental Divide coincide in northern Barnes County; however, south of T. 140 N., the divide is on ground moraine that lacks an integrated drainage system.

Barnes County, located near the geographical center of North America, has a subhumid and continental climate. Winters are severe, and temperatures of -20°F are not unusual, but summer temperatures may exceed 100°F. The average annual temperature at Valley City is 42°F. The average annual precipitation at Valley City is 18.07 inches, most of which falls from May to August, inclusive.

DESCRIPTIVE GEOLOGY

Stratigraphy and Structure of the Preglacial Rocks

PRE-MESOZOIC ROCKS

Little information is available concerning the pre-Mesozoic rocks beneath Barnes County. Test holes have been drilled to the Precambrian granite at scattered localities throughout the State. In northwestern Barnes County an oil test, the Polard and Davis--Guscette No. 1, penetrated granite at a depth of 2,572 feet in the NW1/4NW1/4 sec. 20, T. 142 N., R. 61 W. (Nelson, 1955, p. 5). Wells located in adjacent areas show that the granite surface slopes at the rate of 10 to 15 feet per mile toward the axis of the Williston Basin in northwestern North Dakota.

The log of the Guscette test shows that the granite is overlain by 17 feet of the Deadwood Formation of Cambrian and Ordovician age. The Ordovician System is also represented by the Winnipeg Formation and the Big Horn Group, which are 195 and 560 feet thick, respectively. Shale and sandstone are the principal constituents of the Deadwood and Winnipeg Formations, whereas the Big Horn Group is composed primarily of carbonates. An angular unconformity separates the Ordovician rocks from the overlying Dakota Group of Cretaceous age in the Guscette test hole.

The Pollard and Davis--Gregory No. 1 oil test was drilled in the center of the SE1/4NW1/4 sec. 23, T. 142 N., R. 61 W., approximately 6 miles north of the Guscette test hole. The Gregory test hole penetrated 72 feet of dolomite beneath the Dakota that is questionably identified as part of the Interlake Group of Silurian age by Strassberg (1954, pl. 1). However, Ballard (1963, fig. 7) shows that the Interlake rocks do not extend into Barnes County. If Ballard is correct, the dolomite penetrated by the Gregory test hole probably is part of the Big Horn Group.

MESOZOIC ROCKS

In Barnes County an angular unconformity separates the lower Paleozoic rocks from the overlying Dakota Group of Cretaceous age. The erosional interval is represented by several thousand feet of middle and upper Paleozoic, Triassic, and Jurassic rocks farther west in the Williston Basin. The rocks generally thin toward the flanks of the basin, and were not deposited in the vicinity of Barnes County in as thick a sequence as in the deeper parts of the basin. However, as much as 1,000 feet of rock may have been eroded from the Barnes County area prior to deposition of the Dakota (S.B. Anderson, North Dakota Geological Survey, oral communication).

Dakota Group

This unit is a time-transgressive, continental and littoral deposit that is present in most of the Great Plains states. At the type locality in northeastern Nebraska, these rocks are called the Dakota Sandstone. However, in North Dakota, Hansen (1955, table 3) has used the name Dakota Group and differentiated six formations within the group.

The Dakota Group underlies all of North Dakota, with the exception of parts of the extreme eastern part of the State. The unit does not crop out in North Dakota, but locally, is directly overlain by glacial drift. In Barnes County the Dakota is overlain by more than 400 feet of Upper Cretaceous shale, as well as glacial drift.

Both of the Pollard and Davis test holes completely penetrated the Dakota Group. Sandstone is predominant and strata of siltstone and shale separate the sandstone units. In general, the sandstone is white, medium to coarse grained, and subangular to subrounded. Sand grains are frosted, pitted, and iron stained. Concretions are abundant locally. Nearly equal amounts of sandstone are present in the samples from both test holes. Individual sandstone strata are difficult to correlate, indicating that facies changes are both numerous and abrupt. The interbedded shale and siltstone is medium gray, bentonitic, calcareous, and variegated. As reported by Nelson (1955, p. 4), siltstone is much more abundant in samples from the Guscette test hole than from the Gregory test hole. The Dakota is approximately 450 feet thick in northwestern Barnes County, as shown by the Guscette and Gregory test holes. No other test holes in the county completely penetrated the Dakota. Regional studies indicate that the thickness decreases eastward due to interformational unconformities (Hansen, 1955, p. 25). However, the proportion of sand to finer grain sizes increases toward the east.

Colorado Group

The Dakota Group is conformably overlain by a thick sequence of shale beds. The shale has been divided into two groups, the Colorado Group and the overlying Montana Group. The Colorado Group has been subdivided in this area into four formations, named, from oldest to youngest, Belle Fourche, Greenhorn, Carlile, and Niobrara. The Niobrara crops out in several places in southern Barnes County, but the older formations are known only from well cuttings.

The Belle Fourche Formation is characterized by medium- to dark-gray bentonitic shale that contains abundant *Inoceramus* fragments. The thickness of the Belle Fourche is approximately 200 feet and is consistent throughout Barnes County.

The Greenhorn Formation consists of medium- to dark-gray, calcareous shale that contains numerous white specks and the foraminifer *Globigerina*. Thin strata of very shaly limestone are present locally. In Barnes County, the thickness of the Greenhorn Formation is approximately 150 feet.

The Carlile Formation is composed of dark-gray, noncalcareous, locally bentonitic shale. Fossils and white specks are not present in this formation. It has a uniform thickness of about 200 feet in Barnes County. Although the Carlile does not crop out, it directly underlies the glacial drift in places along the eastern edge of the county (pl. 2, in pocket).

The Niobrara Formation is the only unit in the Colorado Group that crops out in Barnes County. The outcrops were initially included with the overlying Pierre Formation by Upham (1895, p. 91), Leonard (1904, p. 152-153), and Willard (1909, p. 2), but more recent workers correctly assigned them to the Niobrara Formation. The formation is rather poorly exposed along the east wall of the Sheyenne valley near the southern border of the county. However, south of the county line to the town of Lisbon in Ransom County, the formation is well exposed in road cuts in the valley walls. More than 15 test holes drilled in Barnes County east of the Sheyenne River reached the Niobrara, but most of these penetrated only a few feet into the formation. The pattern of subcrop beneath the glacial drift forms a belt approximately 12 miles wide trending north-south across Barnes County (pl. 2).

In southern Barnes and Ransom Counties, exposures of Niobrara consist of light-gray, calcareous, thin-bedded shale, and blocky, argillaceous marl. These rocks are yellowish brown to pale orange on the weathered surfaces. Shale is more abundant than marl, but the shale is often poorly exposed due to its weathering characteristics. The marl is characterized by numerous white specks on the bedding planes, and it usually is exposed in steep slopes or nearly vertical scarps. Well cuttings of the Niobrara consist of light- to medium-gray, calcareous shale with numerous white specks.

The following stratigraphic section is typical of the Niobrara in this area. The section, located in the ditch on the north side of Highway 46 (SE1/4SE1/4 sec. 36, T. 137 N., R. 58 W.), contains the contact of the Niobrara and overlying Pierre Formation (fig. 3).

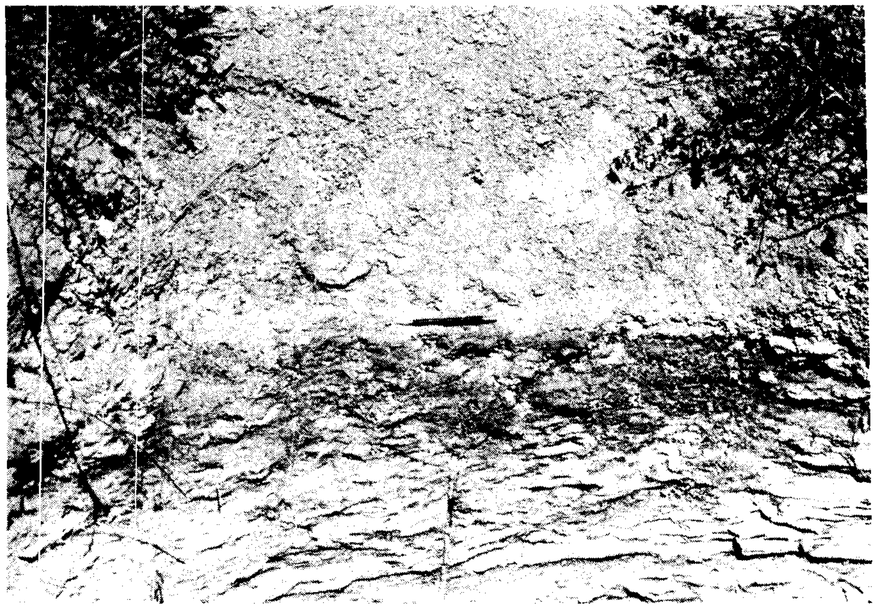

Figure 3. Thin-bedded marl of the Niobrara Formation is conformably overlain by fissile, noncalcareous shale in the Pierre Formation. Pencil lies on contact. Joints in Niobrara contain crystalline selenite.

	Feet
Pierre Formation (lower part)	173.8
Total	173.8
Niobrara Formation:	
Shale, light-gray, calcareous; weathers to yellowish-brown to pale-orange. Gypsum, white to yellowish-orange, earthy to crystalline in bedding planes and fractures	1.0
Marl, light-gray, blocky, hard; weathers to pale-yellowish-orange	.5
Covered; probably soft shale	5.3
Marl, light-gray, argillaceous, blocky; weathers yellowish-orange to orange, white specks on bedding planes	4.7
Total	11.5

Fossils have not been found in the exposures of the Niobrara in Barnes County, although fragmental *Inoceramus* and *Ostrea* are common in Ransom County. Probably foraminifera are present in the exposures, inasmuch as they commonly are found in well cuttings. Madenwald (1962) identified 92 species of foraminifera in the Niobrara of North Dakota. A core of the Niobrara obtained from test hole 142-62-12aad in Stutsman County (Dennis, 1948, p. 18) contained five species. Identification was made by J. A. Cushman (U. S. Geological Survey).

Globigerina cretacea d'Orbigny
Globigerinella aspera (Ehrenberg)
Heterohelix globuslosa (Ehrenberg)
Heterohelix plummera (Loetterle)
Heterohelix pseudotessera (Cushman)

Test-hole data indicate that the Niobrara Formation has a maximum thickness of approximately 250 feet.

Montana Group

The Pierre Formation, basal unit of the Montana Group, conformably overlies the Niobrara, and is overlain by glacial drift in most of the county. The formation underlies the county west of R. 57 W. (pl. 2), and is well exposed in the valley of the Sheyenne River (pl. 1). These exposures were first studied by Upham (1895). Later the Pierre was examined for its ceramic qualities by Leonard (1904, 1906). The deposits were first mapped by Willard (1909) and later described by Kline (1942, p. 352). A detailed study of the microfauna was made by Wilson (1958).

The Sheyenne River has eroded more than 150 feet below the adjacent plains, and exposed thick sections of the Pierre Formation in valley bluffs along the river and major tributary valleys. These exposures extend approximately 25 miles from Valley City southward to the Niobrara contact near the county line. There are no exposures of the Pierre from Valley City to a few miles north of Bald Hill Dam (pl. 1). The formation is exposed in the bluffs above Lake Ashtabula and northward into Griggs County. More than 150 test holes drilled in the area penetrated the Pierre. Most of these were drilled only a few feet into the formation, but several penetrated the entire formation and entered the underlying Niobrara.

Two principal lithologies in the Pierre Formation were recognized. The basal shale unit is characterized by dark-gray to black, fissile, noncalcareous shale with several pale-yellow bentonite beds near the base. Gypsiferous phosphate nodules, manganese concretions, and selenite crystal are present on the outcrops (fig. 4). Average thickness of this unit is about 50 feet. The overlying unit consists of light- to medium-gray, blocky, calcareous shale and argillaceous marl. Two joint systems are well developed in this unit; they strike N. 51° W, and N. 14° E. and dip 72° S. and 90°, respectively. The calcareous shale and marlstone weather pale yellowish gray to brownish gray. The gray color of the Pierre and the absence of white specks in it, readily distinguish the Pierre from the Niobrara.

Figure 4. Fissile noncalcareous member of Pierre Formation. Note numerous manganese concretions on the surface (sec. 4, T. 138 N., R. 58 W.).

Some of the best exposures of Pierre shale in the south-central part of the State are present at the southern edge of the county where Highway 46 crosses the Sheyenne River. More than 170 feet of the lower part of the Pierre is exposed, as is the contact with the underlying Niobrara Formation. The Niobrara-Pierre contact, as well as the lower part of the overlying Pierre, were measured on the east Sheyenne valley wall (SW1/4SW1/4 sec. 31, T. 137 N., R. 57 W.). The upper part of the Pierre is exposed in the west valley wall (SE1/4SE1/4 sec. 36, T. 137 N., R. 58 W.). The following is a composite of the exposed sections.

	Feet
Pierre Formation:	
Shale, dark-gray to black, fissile, noncalcareous	7.4
Marl, pale-gray to medium-gray, blocky, scattered pyritiferous concretions; very argillaceous near top. Weathers yellowish-gray to grayish-brown	58.2
Shale, dark-gray, fissile, slightly calcareous	18
Shale, dark-gray to black, calcareous	3.7
Shale, medium-gray to dark-gray, fissile, noncalcareous	9.5
Marl, pale-gray to brownish-gray; weathers yellowish-gray	4

Shale, dark-gray, fissile, noncalcareous; thin marl bed near center of unit	7.3
Marl, brownish-gray; weathers pale-yellowish-gray; bentonite, yellowish-orange at base	2
Shale, pale-gray to medium-gray; interbedded calcareous, blocky shale and noncalcareous fissile, bentonitic shale; concretions abundant	20.5
Shale, medium-gray to grayish-black, fissile, noncalcareous; phosphate nodules and gypsiferous concretions abundant. Weathers to medium-gray. Few scattered fragmental fossiles. Bentonite, pale-yellowish-orange at .5 and 35.5 feet above base	43.2
Total	173.8
Niobrara Formation	11.5
Total	185.3

Macrofossils are present, but are not common. Several species of *Baculites* and fragmental *Inoceramus* were found in southern Barnes County by Gill and Cobban (1965, p. A-11). Generally these fossils are rather poorly preserved, and are most commonly found in limonitic concretions in the marls and calcareous shales. An abundance of forminifera has been described by Wilson (1958) and Gill and Cobban (1965, p. A-12). Fish scales, also, are abundant locally.

Much of the Pierre Formation exposed in the bluffs of the Sheyenne River has become detached and moved downslope from its original position. This movement occurs by slumping and by earthflow, but slumping is more common in the area of study. The slump blocks move down-slope with a backward rotation in respect to the slope. These blocks are characterized by anomalous dips of the bedding planes or by the dislocation of glacial deposits, which move with the slump block (fig. 5). The movement is slow, and ordinarily only small areas are involved. Slumping is most common in the marl and calcareous shale, and is produced by the natural or artificial oversteepening of the slope.

Earthflows are the movement of soil and underlying weathered shale down the slope. The earthflows are characterized by a hummocky surface broken by fractures in the soil and by a conspicuous buildup of the "toe" or lower edge of the earthflow. Breaks in the soil are most numerous at the toe, but secondary fractures also occur farther up the slope. Generally large areas of the hillside are affected, and the movement is perceptible. Earthflows occur most commonly on the fissile, highly fractured exposures of the Pierre shale. Flowage occurs when an oversteepened slope becomes saturated by abnormal precipitation (fig. 6).

In general, the Pierre Formation thickens westward. The Pollard and Davis -- Guscette No. 1 test well penetrated 286 feet of Pierre shale in sec. 20, T. 142 N., R. 61 W.; however, in this area part of the shale was removed by postdepositional

Figure 5. Slump block of marl from the Pierre Formation has moved downslope with backward rotation in sec. 9, T. 140 N., R. 58 W.

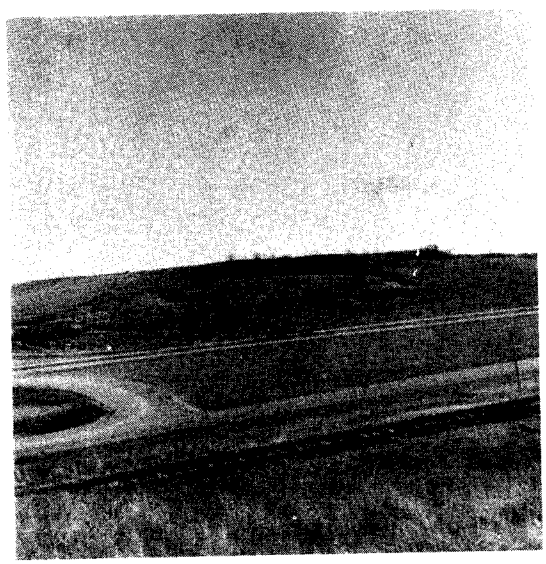

Figure 6. Earthflow on the weathered surface of the fissile, noncalcareous shale in a roadcut along Interstate 94 at Valley City (sec. 29, T. 140 N., R. 58 W.). Tree growth developed in scarp after initial movement.

erosion. Winters (1963, p. 13) reported that the formation is 950 feet thick in Stutsman County. Carlson, Bakken, and Kume (1960, table 1) reported a maximum thickness of 2,200 feet in North Dakota.

None of the Upper Cretaceous and lower Tertiary deposits that overlie the Pierre in western and central North Dakota have been found in Barnes County. The easternmost extent of these formations is 50 miles west of the study area where isolated outliers of the Fox Hills Formation were found in western Stutsman County (Winters, 1963, p. 14). If the Fox Hills, or any of the lower Tertiary formations were deposited in Barnes County, they were removed by subsequent erosion.

Preglacial Bedrock Surface

The preglacial topography of Barnes County had little resemblence to the topography that exists today. The preglacial surface was formed by northeastward-flowing streams according to Flint (1955, p. 139-143) and Lemke and Colton (1958, p. 42-43). A soil profile was developed on the surface, and the upper 9 feet or more of shale was oxidized. Prior to modification by glacial erosion, the bedrock surface was a relatively flat plain that sloped gently toward the east at an average of 15 feet per mile. Bedrock altitudes decrease from 1,450 feet above sea level in T. 143 N., R. 61 W. to less than 900 feet in T. 143 N., R. 56 W. In the vicinity of Litchville and Sanborn, the local relief exceeds 50 feet per mile. However, the lack of detailed test drilling does not permit the interpretation of these features other than as isolated topographic highs and lows.

As the earliest glaciers advanced into central North Dakota, the existing northeastward-flowing streams were diverted toward the south. The capacities of the streams were increased by addition of melt water from the glaciers, and the competence of the streams increased accordingly. Consequently, broad, deep channels were eroded into the shale bedrock in relatively short periods of time. One of these diversion channels crosses western Barnes County and parts of adjacent counties; it was named the Spiritwood valley by Huxel (1961b, p. 179).

The Spiritwood channel is part of a large, southward-trending drainage system having a known drainage area of more than 1,000 square miles in Barnes and adjacent counties (fig. 7). The extremities of the drainage system have not been defined, but it is probable that this was one of the larger preglacial drainage systems in North Dakota. The main channel enters Barnes County in T. 143 N., R. 60 W., and trends south-southwest to the Barnes-Stutsman county line in T. 140 N., R. 61 W. The channel crosses southeastern Stutsman County and enters LaMoure County in T. 136 N., R. 61 W. (Kelly, 1964a, fig. 1).

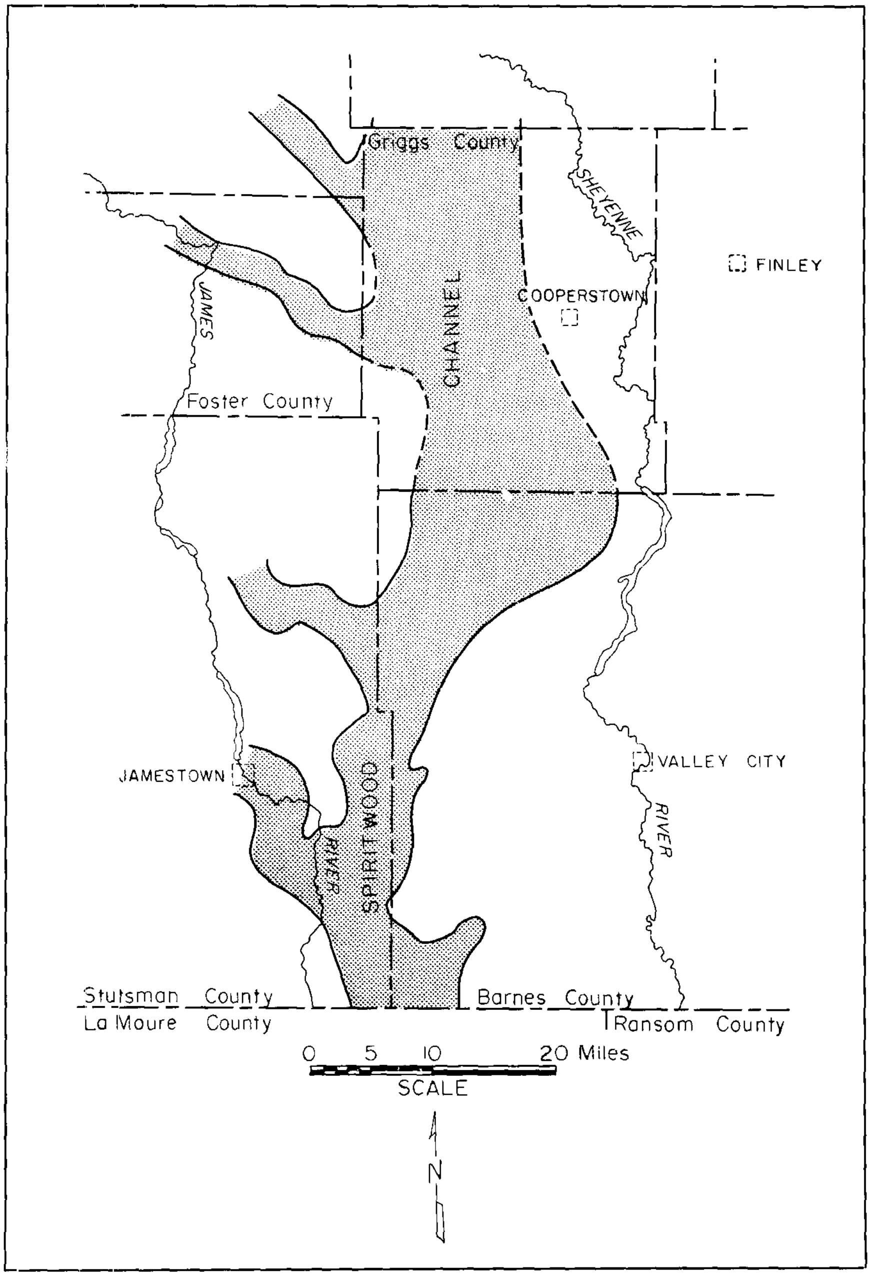

Figure 7. Western Barnes County and adjacent areas, showing area underlain by the Spiritwood channel and tributaries. Compiled from Winters (1963, pl. 2), Kelly (1964a, fig. 1), Bluemle (1965, pl. 2), and unpublished data.

The channel proper was eroded more than 250 feet into the Pierre Formation in Barnes County. As defined by the 1,300-foot bedrock contour, the channel averages 6 miles in width (pl. 2). Test-hole data indicate that the gradient is approximately 3 feet per mile toward the south. This gradient corresponds to the existing gradient of the James River in North Dakota and South Dakota.

Several tributaries join the Spiritwood channel at acute angles, giving the drainage system a dendritic pattern. The gradient of the major tributaries is toward the main channel, and generally in a southerly direction. The major tributaries join the main channel from the west and northwest.

An unusual feature of the bedrock surface is the closed depression that is parallel to the Spiritwood channel in Tps. 140-142 N., Rs. 59-61 W. (pl. 2). This depression, which is more than 10 miles long and about 1-1/2 miles wide, bears little resemblence to a tributary and can best be explained as a glacially-scoured feature.

A channellike bedrock low extends south-southeastward from the closed depression in T. 142 N., R. 59 W. to Vallev City, where it apparently terminates. The orientation of this channel is not compatable with the Spiritwood drainage system. Also, the lack of subsurface control precludes determining the direction and amount of gradient in the channel and the genesis or stratigraphic relationship of the channel to the other bedrock features of the county. Part of this channel has been exhumed by the Sheyenne River northwest of Valley City.

Quaternary Deposits

GLACIAL DRIFT

During the Pleistocene Epoch most of North Dakota was glaciated; only the southwestern corner of the State remained clear of glaciers. Barnes County is entirely within the glaciated portion of the State (fig. 1). Glacial drift in North Dakota has been identified as old as Iowan (?) and as young as Mankato (Lemke and Colton, 1958, figs. 3-5). The county was overridden by the Des Moines ice lobe. Relative positions of the various landforms indicate that the dominate direction of ice advance was from the northeast.

The glacial drift of Barnes County is characterized by a wide range in thickness and lithology. On the basis of data from more than 100 test holes, the average thickness is about 150 feet. The known thickness ranges from 0 to 313 feet. These variations in thickness, which are primarily the result of bedrock irregularities and secondarily the result of glacial deposition, are shown by stratigraphic sections of the county (pl. 3, in pocket).

The greatest thickness of glacial drift (313 feet) was penetrated by test hole 2124 in the NW cor. sec. 6, T. 137 N., R. 57 W. The unusually large thickness is the result of an end moraine development above a bedrock low. Elsewhere, east of the Sheyenne River, the drift has a relatively uniform thickness of about 130 feet, except beneath end moraines where the thickness averages about 200 feet. West of the Sheyenne River, the drift thickens from a featheredge along the river to more than 200 feet in the Spiritwood channel in the western part of the county.

The drift cover in Barnes County consists primarily of glacial till. In general, successive tills cannot be distinguished by lithology; they all are olive gray, sandy to silty, and generally contain large numbers of boulders composed of crystalline rock. The upper 10 feet or more of the surficial till has been oxidized to yellowish brown. Maximum depth of the oxidation is 35 feet in the test hole 2145 located at 143-57-10dcc (Kelly, 1964b, p. 147). In southwestern Barnes County, test hole 2135 (138-61-3aa) penetrated approximately 9 feet of oxidized till at a depth of 60 to 69 feet. This is the only direct evidence of more than one till in the subsurface of Barnes County. The oxidized zone probably was more widespread, but was subsequently destroyed by glacial erosion.

Interbedded with the till are a wide variety of glacioaqueous sediments. Sand and gravel deposits are the most common, and locally they are present in large quantities. The most widespread buried sand and gravel deposit occupies the Spiritwood channel. The deposit, which probably was formed as outwash, averages 50 feet in thickness, but locally exceeds 150 feet. In T. 143 N., the basal part of the outwash is a boulder pavement, which is locally 5 feet thick. Medium to coarse, moderately well-sorted sand and fine to medium gravel are the predominate sediment types in the Spiritwood outwash deposit. Fragmental shale, derived from the local bedrock, is the principal constituent of the coarse sand and gravel deposits; limestone fragments are common, also. Locally the gravel consists of as much as 30 percent crystalline rock fragments. These coarse clastics are overlain in places by a relatively thick sequence of calcareous, clayey silt and interbedded clay. The silt was 64 feet thick in test hole 2075 (142-61-13bbb), as shown on section A-A', plate 3. The silt and clay beds were penetrated north of T. 140 N. only, but may have been much more widespread than they are at present. The Spiritwood outwash underlies an area of at least 320 square miles in Barnes County and adjacent Stutsman County, and extends at least 10 miles farther north in Griggs County (Kelly, 1964a, p. 161).

Most of the test holes drilled in Barnes County penetrated small isolated sand and gravel deposits enclosed within the till. As shown by test drilling in the county, these sand and gravel deposits are usually less than 15 feet thick and seldom exceed 1 square mile in area. Generally, silt deposits enclosed in till are very thin and discontinuous.

The maximum advance of the Des Moines ice lobe is marked by a belt of morainic debris that extends from south-central North Dakota northwestward into Montana (Lemke and Colton, 1958, p. 48). At the time of maximum glacial advance, Barnes County was blanketed by several hundred feet of ice. As a result of various climatic factors, the glacier began to recede; however, this recession was interrupted by numerous pauses or stillstands and minor readvances. Generally, each of these changes in the regimen of the glacier resulted in the development of characteristic landforms that can be attributed to a particular phase of the glacial pause, advance, or recession. The most common landforms include end moraine and associated ground moraine, as well as outwash deposits and various ice-contact features (pl. 1).

At least seven distinct drifts are present in Barnes County (fig. 8). These are named the Sheyenne Valley, Millarton, Eldridge, Buchanan, Kensal-Oakes,

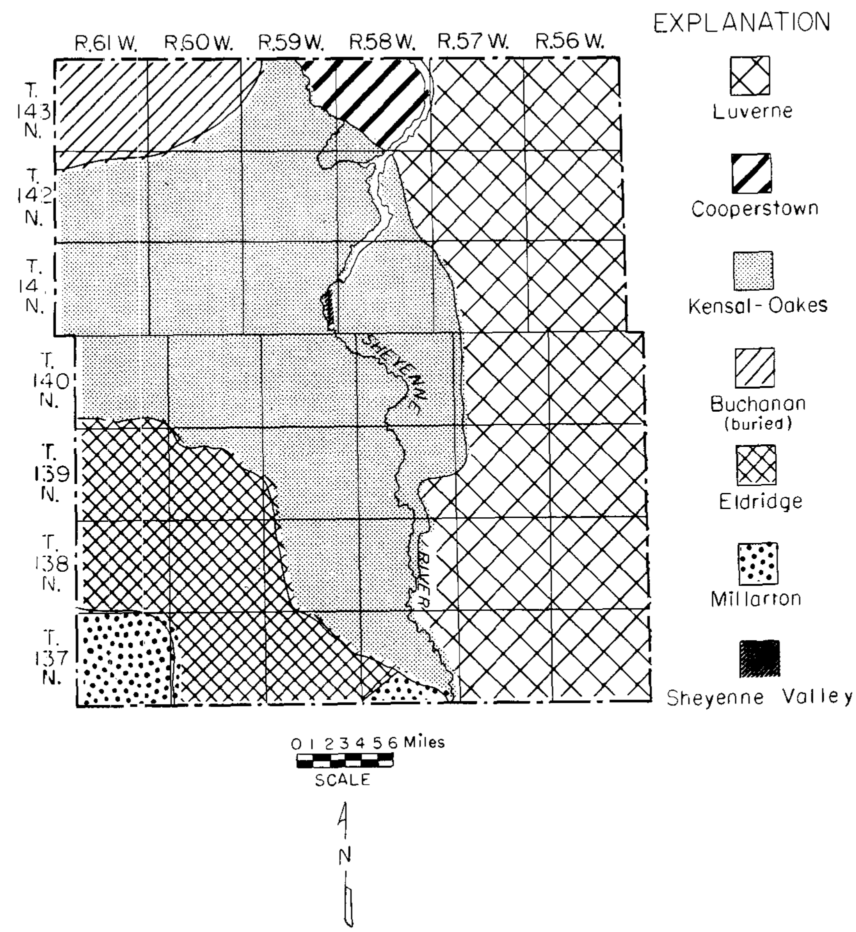

Figure 8. Distribution of the drift units.

Cooperstown, and Luverne drifts. The Sheyenne Valley drift is best exposed in a small area along the valley walls of the Sheyenne River (T. 141 N., R. 59 W.). The Buchanan drift crops out in Stutsman County and probably extends into northwestern Barnes County and adjacent areas to the north (Winters, 1963, p. 56; Block, 1965, p. 79; Bluemle, 1965, p. 22). However, it is overlain by the Kensal-Oakes drift in northwestern Barnes County, and its subcrop area is not definitely known. The other five drifts, named from oldest to youngest, are the Millarton, Eldridge, Kensal-Oakes, Cooperstown, and Luverne. The landforms associated with each of these five drift sheets form most of the topographic features in Barnes County.

Sheyenne Valley Drift

The Sheyenne Valley drift was identified at numerous isolated localities in northern Barnes County, but "it is most completely exposed along the east side of the Sheyenne River valley (Tps. 140 and 141 N., R. 57 W.)." (See Block, 1965, p. 70). The type section was designated as the "south half of the south-east quarter of Section 24, T. 141 N., R. 59 W.****" (Block, 1965, p. 73).

The base of the Sheyenne Valley drift is not exposed in the type locality; consequently, the relationship of the drift to the underlying deposits is not clear. The Sheyenne Valley drift is overlain by the Kensal-Oakes drift and separated from it by a well-developed boulder pavement. Thus, the Sheyenne Valley drift is older than the Kensal-Oakes drift, but the time required for development of the boulder pavement is not known and the difference in age of the two drift sheets is indeterminate. Block (1965, p. 79) suggested that the Sheyenne Valley drift may be "early or sub-Wisconsinan" in age, but the stratigraphic position indicates that the till may be equivalent to either the Millarton or the Eldridge drift sheets, which are late Wisconsin in age. The lack of distinguishing characteristics precludes subsurface correlation of the Sheyenne Valley drift.

At the type locality, the Sheyenne Valley drift is characterized by medium-brown till that contains a large number of shale pebbles and is locally jointed. The following is a description of the exposure at the type locality in the SE1/4 sec. 24, T. 141 N., R. 59 W.:

	Feet
Kensal-Oakes drift ----------	14.1
Total ---------	14.1

Sheyenne Valley drift:

Conglomerate, predominantly well-rounded limestone and acidic crystalline boulders and gravel, sandy; locally well cemented by crystalline calcite; limonite staining common. Grades

laterally into sand, coarse to very coarse; locally cemented by calcite and limonite	1.3
Till-medium-yellowish-brown, oxidized, clayey, compact, calcareous; shale and limestone pebbles abundant, crystalline pebbles generally absent; amorphous gypsum on shale pebbles and moist surfaces	21.9
Covered	8.6
Till, medium-yellowish-brown, silty to sandy, very porous, oxidized; limestone pebbles and boulders abundant, shale and crystalline pebbles uncommon; abundant amorphous gypsum on exposure; grades laterally into till, medium-grayish-brown, mottled dark-brown to white, clayey to silty, compact; two joint systems, N. 45° W. at 70° SE. and N. 20° E. at 90°	19.2
Till, medium-yellowish-brown, very sandy, calcareous; poorly exposed. Slump block of Kensal-Oakes till	7.8
Till, dark-yellowish-brown, clayey, compact, calcareous, oxidized; jointed; shale pebbles abundant, both pebbles and pebble-molds stained by iron and manganese oxide; few limestone and shale cobbles, boulders absent; crystalline rock fragments absent; nodules of white to light-gray amorphous gypsum	5.2
Till, mottled brownish-green to medium-brown, clayey, calcareous, oxidized, very compact; joint systems well developed; shale pebbles abundant, pebbles and pebble-molds stained by iron and manganese oxide, crystalline rock pebbles common, few limestone pebbles	7.4
Till, medium-grayish-brown, very sandy, calcareous, oxidized, friable; shale pebbles abundant, limestone and basic crystalline rock pebbles and boulders present; lenticular poorly sorted sand and very clayey till present locally; exposure partly covered	14.6
Till, dark-yellowish-brown, very sandy, calcareous, oxidized; limestone and crystalline rock pebbles abundant; sand laminae, medium-brown to brownish-black, angular, poorly sorted	1.3
Till, medium-grayish-brown, silty to clayey, calcareous, oxidized, friable; shale pebbles abundant, few limestone and crystalline fragments; small patches of a morphous gypsum; section generally covered, poorly exposed	2.9
Total	90.2

Sediment sizes from the type locality of the Sheyenne Valley drift show that the till is primarily silty to clayey. It contains minor amounts of sand and very little gravel. At the type locality, the lower 18.8 feet of the drift is more sandy than the upper section; lenticular sand strata are common, also. The median diameter of samples from the lower till sequence probably would be within the fine to very fine sand range; whereas, the upper 71.4 feet of the drift would be in the silt to clay range.

The composition of pebbles and larger rock fragments is rather uniform throughout the vertical extent of the type Sheyenne Valley drift. In general, fragments of Pierre shale are the most abundant. These shale fragments usually are within the pebble to cobble range, and most fragments are moderately well rounded. Upon dessication, the shale fragments crack along the shale bedding planes; many of the fragments have fallen from the exposure, leaving a well-formed mold in the till. The molds are usually stained by very dusky-red iron oxide. Grayish-orange-pink to yellowish-gray microcrystalline limestone fragments ranging in size from pebbles to boulders are locally abundant, as are crystalline rock fragments. Fragments of these types generally are larger and more angular than the shale fragments owing to the hardness of limestone and crystalline rocks. Medium-grained granitic rocks are the principal crystalline rock type, but basic igneous and metamorphic rock fragments are present locally. Generally, molds in the till of the limestone and crystalline rocks are not stained.

The depth of oxidization of the Sheyenne Valley drift is difficult to determine. In the roadcut where the type section is exposed, there are several exposures of unoxidized till. The unoxidized till is dark olive gray to olive gray and grades upward into oxidized till that is medium to dark yellowish brown. However, inasmuch as the exposures are on the slope of the valley wall where slumping and soil creep are common, it is not possible to measure accurately the thickness of the oxidized zone.

The Sheyenne Valley drift is the only glacial unit in the county that has a well-defined joint system. Jointing is best developed in the finer grained till units, but the joints are present throughout. Two joint systems were recognized; one system strikes N. 45° W. and dips 70° SE. and the other strikes N. 20° E. and dips 90°. These systems closely correspond to the orientation of joint systems in the Pierre shale. Joints in till in the Sheyenne Valley drift act as avenues of water movement; the joints are stained by manganese oxide and locally contain deposits of amorphous gypsum.

Slightly more than 90 feet of till and associated deposits are exposed at the type locality of the Sheyenne Valley drift, but the base of this drift unit is not exposed. However, Block (1965, p. 73-74) reported that the Sheyenne Valley drift rests directly on the Pierre shale and, in the Sheyenne River valley, has an average thickness of 94 feet. Test holes drilled in the vicinity of the type locality penetrated less than 100 feet of glacial material.

At the type section, a well-developed conglomerate or boulder pavement separates the Sheyenne Valley drift from the overlying Kensal-Oakes drift. It is composed primarily of well-rounded limestone and granitic cobbles and boulders; only minor amounts of interstitial sand are present. Locally, the conglomerate is cemented by coarsely crystalline calcite. The crystals grow toward the interstitial voids, giving a vuggy appearance. The thickness ranges from 0 to 3 feet, and averages approximately 1 foot. This conglomerate probably formed as a lag boulder pavement on the exposed surface of the Sheyenne Valley drift. Much of the fine sediment was removed by wind erosion and the coarser sand and fine gravel fraction was concentrated by slope wash.

The Sheyenne Valley drift has been recognized in the Sheyenne River valley and its tributaries, as well as at isolated localities elsewhere in north-central Barnes County (Block, 1965, pl. 1). Most of the exposures are on valley walls or morainic slopes that postdate glaciation in the Sheyenne Valley. Consequently, the Sheyenne Valley drift does not have its own topographic expression and no landforms can be ascribed to this drift sheet.

Millarton Drift

The name Millarton drift was applied by Winters (1963, p. 48) to moraine deposits in southern Stutsman County. The end moraine is small and poorly defined in the vicinity of Millarton, N. Dak., but the associated ground moraine is exposed at the surface in southeastern Stutsman County. Two small areas of Barnes County are underlain by the Millarton drift (fig. 8). The Millarton moraine probably corresponds to the "outer" unit of the Antelope moraine of Hard (1929, p. 28). It is one of the oldest drift units on the Drift Prairie of North Dakota (Lemke and Colton, 1958, p. 49), and is the oldest drift unit widely exposed in Barnes County. The Millarton drift was not deposited from an advancing glacier, but was laid down as the ice receded toward the northeast.

Ground moraine and washboard moraines are the only landforms associated with the Millarton drift in Barnes County.

Physical characteristics.--In Barnes County the Millarton drift sheet consists primarily of till. The till is composed largely of sandy to clayey silt that is medium yellowish brown and moderate to very calcareous. Moderate quantities of rock fragments are contained in the till. Median size of the till is approximately 0.032 mm, which is within the medium silt range. Angular to subangular limestone and granitic pebbles and boulders are the most abundant rock fragments contained in till of the Millarton drift. Shale fragments are present in minor quantities. There is no apparent difference in lithology of the till at the two areas in Barnes County where the till of the Millarton drift is exposed. Similarly, the lithology of the till in Barnes County resembles the lithology described by Winters (1963, p. 30) at the type locality.

The upper 17 feet of the Millarton drift was found to be oxidized in a test hole drilled in the SW cor. sec. 36, T. 137 N., R. 59 W. No other test holes have been drilled through the Millarton drift where it is exposed at the surface, but based on surficial observations, it is probable that the depth of oxidation averages about 17 feet.

The Millarton drift sheet is relatively thin in Barnes County. Test hole 137-59-36ccc, in the south-central part of the county, penetrated 32 feet. In a test hole drilled through the Eldridge and the underlying Millarton drift sheet in sec. 3, T. 138 N., R. 61 W., the Millarton deposits were 28 feet thick. The older drift was readily distinguished from the upper glacial unit by an oxidized zone 4 feet thick that was formed on till of the Millarton drift. The upper part of the oxidized zone probably was eroded by subsequent glaciation; consequently, the true thickness can only be inferred. Assuming that the oxidized zone was originally 17 feet thick, then the Millarton drift was approximately 45 feet thick when deposited. Winters (1963, p. 49) reported that the thickness of this drift in Stutsman County ranges from less than 50 feet to more than 200 feet. In both test holes drilled through the Millarton drift in Barnes County, the drift sheet lies directly on the Pierre Formation.

Till landforms.--Ground moraine and a few isolated washboard moraines are the only landforms associated with the Millarton drift sheet in Barnes County. Millarton end moraine is found only in adjacent counties west of the study area.

The term "ground moraine" applies to those glacial deposits composed primarily of till that has a gently undulating topography lacking a preferred orientation of landforms. Generally the topographic relief is less than 50 feet per square mile. The moraine was deposited beneath a moving glacier or is the residue left by melting ice.

Two areas of Millarton ground moraine are present in Barnes County. The larger of the areas is in T. 137 N., R. 61 W., southwestern Barnes County. This area is bounded on the north by a series of rather indistinct Eldridge end moraines. The eastern boundary is arbitrarily defined as the outwash channel trending southward across T. 137 N., R. 60 W. (pl. 1). The area extends into LaMoure and Stutsman Counties on the south and west, respectively. The other area of Millarton drift is in T. 137 N., Rs. 58 and 59 W. The Eldridge end moraine borders the area on the northwest and the Kensal-Oakes end moraine on the northeast (pl. 1). Most of the Millarton drift in this area is overlain by outwash associated with the Kensal-Oakes drift, but the morainal deposits are exposed locally at the surface and in roadcuts along Highway 46.

Ground moraine associated with the Millarton drift is characterized by relatively flat topography; the relief is usually less than 20 feet per square mile. There is little integrated drainage on the western-most morainal area, and most of the surface runoff collects into shallow undrained depressions or sloughs. The Continental Divide crosses the county between the two areas of Millarton ground moraine; the ground moraine in southwestern Barnes County is in the Missouri drainage area, whereas the moraine in the south-central part of the county is in the Hudson Bay drainage system. An ephermeral stream traverses the Millarton moraine in south-central Barnes County and has breeched the Eldridge end moraine by headward erosion. This unnamed stream, which empties into the Sheyenne River in Ransom County, carries water only during periods of heavy rainfall.

Washboard moraines are present on the Millarton drift surface in the southwestern corner of the county. These linear ridges were formed as the receding glacier made temporary pauses in its recession. Along the ice front, glacial till accumulated to greater thicknesses than in intervening ground moraine areas. Consequently, the ridges are at right angles to the ice front and show the direction of glacial retreat. The relief on the washboard moraines is usually less than 10 feet. Consequently, the ridges are difficult to recognize on the ground, although they are readily apparent on aerial photographs. These low moraines have an arcuate pattern that is convex toward the southwest, indicating that the glacial withdrawal was northeastward.

Eldridge Drift

Todd (1896, p. 45-47), Willard (1909, p. 3), and Kresl (1955) described a morainal area in central Stutsman County called the "Antelope" and (or) the "Third" moraine. Winters (1963, p. 50) proposed the name Eldridge for the same drift sheet where it is well developed near the town of Eldridge, N. Dak. The Eldridge drift forms the surface deposits throughout much of southeastern Stutsman County and extends into Barnes County. It covers about 240 square miles in the southwestern part of the county (fig. 8). This drift sheet was deposited as the melting ice receded from the position it occupied during Millarton time. Therefore, the Eldridge drift is younger than the Millarton drift, but older than the other units widely exposed in the county.

A variety of landforms are associated with the Eldridge drift in Barnes County. The till landforms include end moraine, recessional moraine, ground moraine, and washboard moraine. The stratified drift landforms include both outwash and ice-contact features.

Physical characteristics.--The Eldridge drift consists primarily of glacial till in Barnes County. The till is composed of sandy to clayey silt that is moderately to very calcareous and cohesive. Median size of the till constituents is approximately 0.028 mm, which is within the medium silt range. Locally, selenite crystals are abundant on exposures of the till. Thin beds of poorly sorted sand are common in the Eldridge drift. These sand bodies are discontinuous and seldom more than 0.5 foot in thickness. Angular granitic pebbles and cobbles are the most common rock type that occur as inclusions in the till, but metamorphic rocks, lignite fragments, and subrounded pebbles of shale are locally abundant. Granitic and metamorphic boulders are rather common on the surface, but they are not as numerous as in other drift sheets. The oxidized till is grayish orange to moderate yellowish brown in color, whereas the unoxidized till is olive gray to olive black. The zone of oxidation developed in the upper part of the Eldridge drift averages 18 feet in thickness. This average is based on data from 28 test holes. The maximum thickness of oxidation is 28 feet in test hole 2121 (138-61-31bbb).

The Eldridge drift sheet averages about 75 feet in thickness. The greatest thicknesses were penetrated by test holes drilled into the buried Spiritwood deposits in the western part of the county (fig. 7) and by test holes drilled near Litchville in southwestern Barnes County. The drift sheet thins toward the north and east. Locally it is less than 10 feet thick.

The stratified drift landforms associated with the Eldridge drift are composed primarily of sand and gravel. Silt and clay are only minor constituents. In general, the sand is medium to fine grained, poorly sorted, and silty; the gravel is fine to coarse grained, poorly sorted, and is composed principally of subrounded to rounded crystalline rocks. The sand and gravel are interbedded, and abrupt facies changes are common. Locally the deposits are cemented by calcite and limonite. Iron oxide staining is abundant locally.

Till landforms.--Numerous till landforms are developed on the Eldridge drift. These include end moraine, ground moraine, and washboard moraine.

An end moraine is a ridgelike accumulation of glacial drift that was built along the margin of a glacier (Flint, 1957, p. 13). These features represent marginal thickenings of the drift sheet produced when the ice front stabilized. The Eldridge end moraines were built during pauses in the glacial retreat from the Millarton position. In Barnes County, the Eldridge end moraines are small and discontinuous (pl. 1).

The western segment of end moraine, located in T. 137 N., R. 61 W., consists of linear belts of drift oriented east-west. They have an average width of a quarter of a mile. In general, the proximal and distal margins of these moraines are well defined, but the ends are transitional with the adjacent ground moraine. They have distinct crests for much of their length, which rise nearly 40 feet above the surrounding ground moraine.

Another belt of Eldridge end moraine extends southwestward from sec. 18, T. 137 N., R. 58 W. into LaMoure County. The average width is about three-quarters of a mile, and the maximum width in Barnes County is approximately 1-1/2 miles. The proximal edge of the morainic belt is well defined near its northern end, but farther south it merges with the ground moraine. This segment of end moraine lacks a distinct crest for most of its length. Instead, it is characterized by discontinuous topographic highs and numerous closed depressions. Locally the hills rise more than 50 feet above the adjacent depressions.

A belt of Eldridge end moraine, which consists of discontinuous, irregular, elongate hills, extends across T. 139 N. Rs. 60 and 61 W. (pl. 1). The average width of this segmented belt is a quarter of a mile. The margins of the end moraine are well defined locally, but generally they are transitional with the adjacent ground moraine. Those segments at the southeastern end of the moraine are most obvious and have clearly defined crests. Several parts of the moraine are more than 40 feet higher than the ground moraine, but generally the topographic relief on the end moraine does not exceed 30 feet.

Ground moraine is the most extensive landform associated with the Eldridge drift sheet. The ground moraine extends north and eastward from the Eldridge end moraine to the Kensal-Oakes end moraine, and westward into Stutsman County (pl. 1). The Eldridge ground moraine has less relief than any of the other drift sheets in the county; it generally is less than 20 feet per square mile. There are few closed depressions or potholes, and most of them do not exceed 5 feet in depth.

An integrated drainage system has not developed on the ground moraine, except in T. 137 N., R. 59 W. where headward erosion has extended two intermittent streams and their tributaries through the Eldridge end moraine. Other intermittent streams in the area are associated with the proglacial landforms.

In Stutsman County, the Eldridge drift sheet is characterized by a large number of washboard moraines (Winters, 1963, p. 52). These moraines are well developed in the vicinity of Jamestown, but they become less numerous eastward. A small concentration of washboard moraines occurs in T. 137 N., R. 59 W., east of Litchville, near the proximal edge of the Eldridge end moraine. The relief on the washboard moraines is usually less than 10 feet per square mile and they are difficult to distinguish on the ground. These moraines are convex toward the southeast, which indicates that, in this area, the Eldridge ice front receded toward the northwest and the north.

Stratified drift landforms.--Stratified drift landforms associated with the Eldridge drift consist of an outwash plain, 2 outwash channels, and 3 ice-contact features.

Outwash consists of stratified drift that was transported from a glacier by melt water. Where melt-water streams were confined, the sediment was deposited in a channel. Where the melt water left the confining channel, large quantities of outwash were transported beyond the channel and deposited as an outwash plain.

There are two outwash features associated with the Eldridge moraines in Barnes County, as well as several ice-contact features that resemble crevasse fillings.

In the northwestern part of T. 137 N., R. 60 W., an outwash plain was formed by water flowing southward from the glacier during the Eldridge stage. This outwash plain is flat to gently rolling, with a maximum relief of about 10 feet per mile. Commonly the closed depressions are occupied by sloughs. An outwash channel extends southward from the plain and into LaMoure County. The channel width averages a quarter of a mile, and the channel depth increases southward. In sec. 31, T. 137 N., R. 60 W., the bottom of the channel is approximately 30 feet below the adjacent ground moraine. A second outwash channel extends from secs. 14 and 15, T. 138 N., R. 61 W. south-southwest and enters Stutsman County. The width of this channel is approximately half a mile where it leaves the county. Both of the Eldridge outwash channels are now occupied by intermittent streams.

Ice-contact features are those landforms that were produced in close proximity to the glacier. Each type is named according to its mode of origin; the principal types are kames, eskers, and crevasse fillings. Kames are mounds composed primarily of stratified sand and gravel that was deposited by melt water on the glacier or at its edge (Holmes, 1947, p. 248). As the supporting ice melted, the deposits slumped and were left as irregular shaped hills. Stream deposits that accumulated on or below a glacier are called eskers. These landforms are long, narrow, sinuous deposits comprised of stratified drift, and generally are oriented normal to the direction of ice movement. Crevasse fillings are landforms composed of glacial drift that accumulated in large fractures, or crevasses, in the glacier. Crevasse fillings are often long, narrow ridges oriented parallel to the ice front.

Three ice-contact features were deposited on the Eldridge ground moraine; these features, which resemble crevasse fillings, are located in the S1/2 of T. 138 N., R. 60 W. These features rise about 15 feet above the surrounding ground moraine, but they grade into the moraine and are not readily apparent in the field. Road cuts through the features in sec. 35, T. 138 N., R. 60 W. show that they are composed of stratified sand and gravel overlain by a thin veneer of till.

Buchanan Drift

An arcuate belt of end moraine, extending across north-central Stutsman County, was named the Buchanan moraine by Winters (1963, p. 55). The Buchanan moraine probably was deposited in the northwestern part of Barnes County, also, but it was later buried beneath the Kensal-Oakes drift (fig. 8).

Test holes drilled in the area supposedly underlain by Buchanan drift failed to yield conclusive evidence of a buried drift sheet. No lithologic changes were apparent in the test-hole samples, and no buried soil profiles were penetrated. However, the Buchanan moraine probably was deposited in the county, but the time interval prior to the deposition of the Kensal-Oakes drift was too short to allow development of a weathered zone in the Buchanan drift.

Several lines of evidence suggest the presence of the Buchanan drift in Barnes County: (1) The same ice sheet that deposited the Millarton and Eldridge drifts in the county also deposited the Buchanan moraine (Winters, 1963, p. 58). Therefore the mechanism was available for the development of another moraine. (2) Extrapolation of the moraine as mapped by Winters would extend it into northwestern Barnes County. (3) Most of the test holes drilled in the southeastern part of T. 143 N., R. 60 W. and the northern half of T. 142 N., R. 60 W. penetrated a widespread sand and gravel deposit (Kelly, 1964b). This deposit, which ranges in thickness from less than 1 foot to more than 25 feet, possibly represents a buried outwash plain associated with the Buchanan moraine. (4) Block (1965, p. 80) identified "Buchanan(?)" in northwestern Barnes County and reported that the lithology and the calcium carbonate content of the till were different from that of the surrounding till.

Kensal-Oakes Drift

The most widespread drift sheet in Barnes County is the Kensal-Oakes (fig. 8). Hard (1929, p. 31-32) applied the name Oakes moraine to that part of the drift sheet in south-central North Dakota, and Lemke and Colton (1958, p. 50 and fig. 5) referred to the unit as the Oakes moraine in south-central North Dakota but applied the name Kensal moraine in central North Dakota. Winters (1963, p. 61) and Bluemle (1965, p. 33) referred to this drift as the Kensal moraine. Inasmuch as Barnes County is located about midway between the two type areas, the name Kensal-Oakes moraine is applicable.

The southwestern edge of the Kensal-Oakes drift sheet extends from sec. 31, T. 140 N., R. 61 W. at the Barnes-Stutsman County boundary to the vicinity of Kathryn (T. 137 N., R. 58 W.). Approximately 680 square miles of the county north and east of this line are blanketed by the Kensal-Oakes drift sheet (pl. 1). The drift was deposited during a significant readvance of the glacier following the formation of the Buchanan moraine. Consequently, the Kensal-Oakes drift is younger than the units previously described, but it is older than the Cooperstown and Luverene moraines (fig. 8).

Physical characteristics.--Glacial till is the principal constituent of the Kensal-Oakes drift. The till is composed of silty to clayey sand that is moderately calcareous and cohesive to friable. The oxidized till is very pale orange to pale yellowish brown, whereas the unoxidized till is olive gray. Median size of the till ranges from 0.062 mm to 0.250 mm, but the average is in the range of very fine sand (0.08 mm). These values are compatible with the analyses of till of the Kensal-Oakes drift in Stutsman County (Winters, 1963, p. 31) and in Foster and Eddy Counties (Bluemle, 1965, p. 16). Stratified sand and gravel deposits commonly are interbedded with the till. These range in thickness from a few inches to several feet, but generally they have little areal extent. Rock fragments contained in the till are primarily subrounded to rounded pebbles and cobbles of shale derived from the underlying bedrock formations. About 70 percent of the rock fragments are shale, but several samples indicated as much as 95 percent shale. Angular to subrounded crystalline and limestone cobbles and boulders also are present in the till, generally in quantities of less than 30 percent. The average thickness of oxidation in the Kensal-Oakes drift is 14 feet, but ranges from 8 to more than 20 feet.

The Kensal-Oakes drift sheet is rather thin. South of Valley City, the Sheyenne River valley is eroded into bedrock, and less than 40 feet of drift is exposed at the tops of the valley walls. The average thickness of drift penetrated by test holes in T. 140 N., R. 60 W. was 37 feet, but the lower part probably is buried Eldridge drift. Less than 20 feet of till covers the buried outwash in T. 142 N., R. 60 W. These data indicate that the Kensal-Oakes drift has an average thickness of less than 50 feet, except in the end moraine areas where it is generally less than 100 feet thick.

An anomalous feature of the drift is the inclusion of masses of a foreign till within the Kensal-Oakes drift. These inclusions are grayish orange, very calcareous, cohesive, clayey silt containing abundant limestone fragments. Subangular to subrounded limestone pebbles and boulders comprise about 70 percent of the included rock fragments. The grayish-orange till does not support the abundant and varied vegetation common to the Kensal-Oakes till. Detailed analyses of these two units indicate that they are of different origin, and that the grayish-orange till was incorporated into the younger Kensal-Oakes till by glacial action (Kelly and Baker, 1966).

Sand and gravel are the principal constituents of the stratified drift landforms associated with the Kensal-Oakes drift sheet. The sand is medium to coarse grained, subangular, and poorly sorted. The sands are usually crossbedded and contain thin laminae of silt and clay. The gravel is poorly sorted and sandy, and the beds are discontinuous. Subrounded to rounded granitic and carbonate rocks are the predominate gravel constituents. Size of the gravel ranges from pebbles to boulders more than 2 feet in diameter. Large boulders are common in outwash channels and are less common in ice-contact features.

Till landforms.--The till landforms associated with the Kensal-Oakes drift sheet are end moraine, washboard moraine, and ground moraine. In Barnes County, the Kensal-Oakes end moraine can be conveniently subdivided into two segments. The northern segment enters the county in T. 142 N., R. 61 W. from Stutsman County, and extends in an arcuate belt south and east to T. 139 N., R. 59 W. south of Hobart Lake. The southern segment extends from the Hobart Lake area southward to T. 137 N., R. 58 W. (pl. 1). Although the average width of the moraine is about 2 miles, the maximum width exceeds 4 miles. It is very irregular discontinuous, and is characterized by strongly rolling topography of high hills separated by numerous closed depressions. The relief averages 60 feet per mile, but locally it exceeds 120 feet. There is no clearly defined axial ridge, except in the southern part of T. 139 N., R. 59 W. where the moraine is less than 1 mile wide. The distal boundary is locally well defined owing to the nearly flat topography of adjacent outwash features. The proximal boundary is poorly defined, and the end moraine grades rather imperceptibly into the adjacent ground moraine.

The two segments of end moraine, both of which are convex toward the southwest, indicate that the moraine was formed by two separate ice lobes. The junction of the lobes was in the vicinity of Hobart Lake where the end moraine segments join.

A number of washboard moraines were formed on the Kensal-Oakes ground moraine in T. 140 N., Rs. 60 and 61 W. (pl. 1). These moraines are randomly scattered, but they are all convex toward the southeast, south, or southwest, generally parallel to the nearby end moraine. Relief on the washboard moraines locally exceeds 30 feet per mile, but it is generally less than 20 feet per mile.

Ground moraine covers most of the county north and east of the Kensal-Oakes end moraine and south and west of the Cooperstown and Luverne moraines. This area is characterized by moderately to gently rolling topography. Relief on the ground moraine generally does not exceed 30 feet per mile and locally is less than 10 feet per mile. Shallow, closed depressions, 10 feet deep or less, are common.

In places the Kensal-Oakes ground moraine is modified by flutings. Flutings are defined as ridge and groove landforms "produced by stream-line flow of glaciers, which molded the subglacial floor through various combinations of erosion and deposition" (Flint, 1957, p. 66). More recently these have been called drumlins (Colton and Lemke, 1955; Aronow, 1959). Two groups of drumlins, or flutes, are developed on the Kensal-Oakes ground moraine, one in T. 142 N., R. 60 W., near Leal, and the other in T. 138 N., R. 58 W., about 10 miles south of Valley City. The crests of the Leal drumlins rise approximately 20 feet above the till plain and are oriented N. 55° E. (fig. 9). The drumlins in T. 138 N., R. 58 W. are about the same height but are oriented N. 65° E. Glacial till is the principal constituent of the drumlins, although several of these features in secs. 3 and 4, T. 142 N., R. 60 W., are underlain by stratified drift. Orientation of the drumlins is parallel with the direction of the last ice movement. The drumlin complexes having distinct orientations gave supporting evidence that two separate ice lobes traversed Barnes County during Kensal-Oakes time.

Stratified drift landforms.--The largest outwash system in Barnes County is associated with the Kensal-Oakes drift sheet. Herein called the Stoney Slough outwash system, it consists of numerous small tributary channels that head in the Kensal-Oakes end moraine and extend across the Eldridge ground moraine. The tributaries coalesce in the northeast part of T. 138 N., R. 60 W. to form an outwash plain of several square miles. The Stoney Slough channel extends southeastward along the front of the Kensal-Oakes end moraine, but widens to form

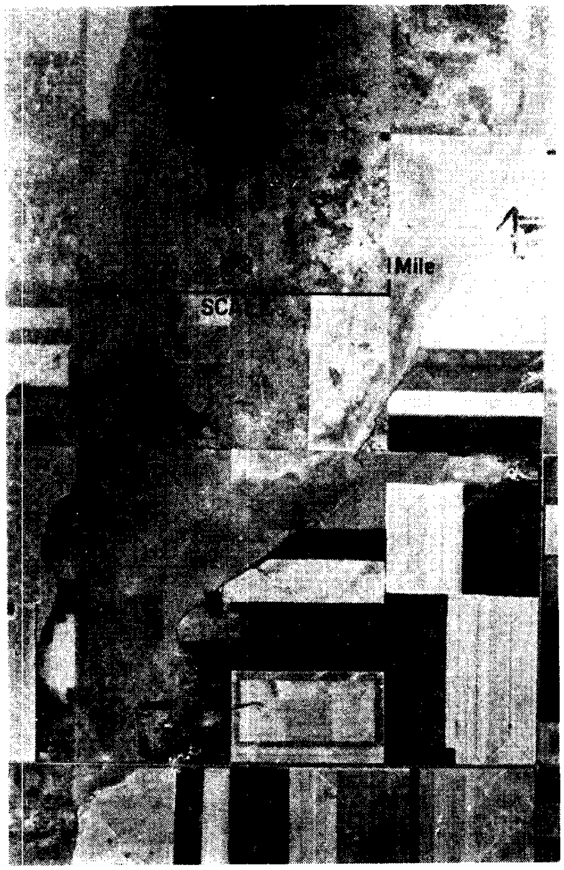

Figure 9. Drumlins in the lower part of the photograph locally rise more than 20 feet above the adjacent ground moraine. The drumlins are flanked on the northwest by the bed of a former lake (T. 142 N., R. 60 W.).

another outwash plain in T. 137 N., R. 58 W. This plain extends into Ransom County and is locally called the Sand Prairie.

The tributaries to the Stoney Slough outwash system have average widths of approximately a quarter of a mile and are characterized by chains of lakes and sloughs. The channels are eroded as much as 60 feet below the adjacent end moraine surfaces, but are less deeply eroded where the channels traverse ground moraine. The Stoney Slough channel has been eroded about 20 feet below the surrounding terrain and has an average width of approximately 1 mile. Stoney Slough is now occupied by an intermittent stream.

A melt-water channel located in Tps. 139-140 N., R. 61 W., which traverses the Kensal-Oakes end moraine and crosses Eldridge ground moraine, is occupied by a chain of lakes and sloughs (fig. 10). The origin of this channel is similar to that of the Stoney Slough outwash system. Other outwash channels associated with the Kensal-Oakes drift sheet were formed as the glacier retreated northeastward. They are rather well developed in the vicinity of Wimbledon in northwestern Barnes County. Most of these outwash channels are indistinct, owing to the shallow depth to which they were eroded below the adjacent drift surface. Generally, the channels are less than 10 feet deep, although locally they may be as much as 40 feet deep.

One of the characteristics of the Kensal-Oakes drift sheet is the large number of ice-contact features associated with it. More than 50 kames are included in the Kensal-Oakes drift. They are especially abundant in the vicinity of the end moraine in Tps. 139 and 140 N. In T. 138 N., R. 59 W., a large kame complex was de-

Figure 10. A chain of lakes occupies a Kensal-Oakes outwash channel in Tps. 139-140 N., R. 61 W. Island Lake is at the top of the photograph.

posited by part of the melt water that drained southward through Stoney Slough. The other kames are randomly located on the drift sheet.

The kames display a wide range of topographic form, ranging from conical shaped hills to low ground swells (fig. 11). Many of these features rise more than 80 feet above the surrounding terrain. The abundance of these features indicates that large quantities of melt water and debris were made available by the melting of the Kensal-Oakes glacier.

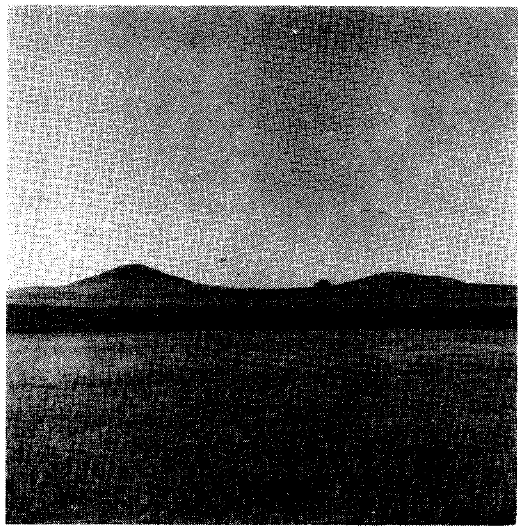

Figure 11. Well developed kames in the Kensal-Oakes end moraine in sec. 6, T. 139 N., R. 59 W. rise more than 80 feet above the surrounding area. View is toward the northeast.

One of the larger esker complexes in North Dakota is in T. 143 N., Rs. 60 and 61 W. in northwestern Barnes County. It consists of two large southwestward-trending eskers that coalesce in the vicinity of Wimbledon (pl. 1). The north limb trends S. 35° W for more than 5-1/2 miles. It has a maximum height of 80 feet, but the average height is about 40 feet (Block, 1965, p. 20). The south limb trends S. 65° W. for about 8 miles. Locally this esker bifurcates and consists of two sub-parallel eskers having a maximum height of about 50 feet. Several smaller, discontinuous ice-contact features are located on the ground moraine that separates the two eskers. The Wimbledon esker complex was formed by two southwestward-flowing subglacial streams. A deep outwash channel extends southwestward beyond the junction of the two eskers into Stutsman County as part of the Sevenmile Coulee drainage (Winters, 1963, p. 74).

A group of small eskers is located primarily in T. 142 N., R. 59 W. Only one of these eskers is more than 2 miles in length and none of them rise more than 10 feet above the adjacent Kensal-Oakes ground moraine. They are subparallel and trend about S. 45° W.

Two lake plains are genetically related to the Kensal-Oakes drift. These lakes formed on the Kensal-Oakes till plain soon after the ice retreated toward the northeast. The larger was located principally in sec. 33, T. 143 N., R. 60 W., sec. 4, T. 142 N., R. 60 W., and adjacent sections (pl. 1). At maximum pool, the lake was about 10 feet deep and had a surface area of more than 3 square miles. Approximately 4 feet of yellowish-gray, clayey, thinly-laminated silt accumulated in the lake basin. The lakebed is very flat, having less than 3 feet of relief per mile. In wet years a slough occupies much of the lake plain; consequently, much of the plain is not cultivated (fig. 9).

A similar, but somewhat smaller, lake was located in sec. 11, T. 141 N., R. 60 W. near Rogers. This lake was approximately 5 feet deep and had an areal extent of less than 1 square mile. Less than 1 foot of silt accumulated in this lake.

Cooperstown Drift

The type area of the Cooperstown drift is in the vicinity of Cooperstown, a village located approximately 15 miles north of the Barnes County boundary. The name was used first by Lemke and Colton (1958, p. 51 and fig. 5), and later by Colton, Lemke, and Lindvall (1963).

In Barnes County the Cooperstown drift covers an area of approximately 30 square miles northeast of Baid Hill Creek and west of Lake Ashtabula (fig. 8). This drift sheet was deposited after the glacier had retreated from the Kensal-Oakes position, but prior to the readvance to the Luverne position. Probably the Cooperstown drift was deposited over a much wider area than its present outcrop area, but has been covered by younger drift deposits.

The landforms associated with the Cooperstown drift are end moraine, ground moraine, and an outwash channel.

Physical characteristics.--Till of the Cooperstown drift is composed of calcareous, cohesive, sandy silt. The oxidized till is yellowish orange, whereas the unoxidized till is olive gray. Median size of the till constituents is approximately 0.060 mm, which is within the coarse silt range. Discontinuous sand and gravel lenses are present in the till, but most are less than a foot thick. Granitic and metamorphic rock cobbles and boulders are numerous in the till, and many of the cultivated fields are littered with them. The average thickness of the oxidized zone in the Cooperstown drift is 15 feet, on the basis of data obtained from three test holes.

Thickness of the Cooperstown drift sheet averages less than 20 feet in the test holes that have penetrated the unit. A test hole in the NE cor. sec. 1, T. 143 N., R. 59 W., penetrated 144 feet of drift, but most of this drift was deposited in the

Spiritwood channel prior to glaciation represented by the Cooperstown drift. Other test holes penetrated thin sequences of drift directly overlying the shale bedrock.

Till landforms.--The Cooperstown end moraine extends southeastward from sec. 2, T. 143 N., R. 59 W., to Lake Ashtabula in the southeastern part of T. 143 N., R. 58 W. (pl. 1). The end moraine is less than 8 miles long and cannot be traced into Griggs County on the north. The average width of the end moraine is about 1-1/2 miles. The moraine is bounded by post-Cooperstown lake plains and by the valley of Bald Hill Creek. There is no clearly defined crest of the moraine; the axis consists of a lineation of hills and separating low areas. Locally the hills rise more than 75 feet above the low areas, but the average relief is less than 50 feet. Owing to the positions of the adjacent lake plains, both the distal and proximal boundaries of the end moraine are clearly defined.

Nearly half of the ground moraine in Barnes County that is associated with the Cooperstown drift sheet is buried beneath younger lake deposits. The exposed ground moraine is gently rolling to nearly flat and has a maximum relief of less than 30 feet per mile. The relief in much of the area does not exceed 10 feet per mile; this is attributed to wave erosion in lakes that once occupied the area. Much of the drift sheet is littered by cobbles and boulders that were concentrated by frost heaving and wave action in the once existent lakes. The ground moraine contains few closed depressions; however, neither is it well drained.

Stratified drift landforms.--Bald Hill Creek originated during the Cooperstown phase of glaciation in the form of a proglacial outwash stream. Headwaters of the stream were approximately 40 miles northwest in Eddy County. The stream flowed southeastward along the front of the Cooperstown moraine to sec. 19, T. 143 N., R. 58 W. where Bald Hill Creek makes a sharp, anomalous turn toward the southwest (pl. 2). This anomaly is the result of stream diversion by a bedrock high located in T. 143 N., R. 58 W. The bedrock high was breeched by the stream in sec. 1, T. 142 N., R. 59 W. where the channel reversed its course to the east-northeast. At the present junction of Bald Hill Creek and Lake Ashtabula, the outwash stream turned south and began eroding the channel now occupied by the Sheyenne River. Thus, Bald Hill Creek was the master stream during glaciation.

Luverne Drift

The Luverne moraine was first mapped by Upham (1895, p. 158) as the Eighth or Fergus Falls moraine. In a summary of the Pleistocene geology of North Dakota, Lemke and Colton (1958, p. 5) correlated part of the moraine with the Cooperstown, but did not map the full extent of the moraine. More recently the moraine was mapped accurately by Colton, Lemke, and Lindvall (1963); however, it was not named. Owing to the confusion of earlier terminology, Block

(1965, p. 89) proposed the name Luverne moraine for this end moraine and the Luverne drift for the associated drift sheet. Type area is the vicinity of Luverne, N. Dak., a small village located in sec. 32, T. 144 N., R. 57 W., southwestern Steele County.

Approximately 520 square miles of eastern Barnes County is covered by the Luverne drift (fig. 8). Thus, in the county, it is second only to the Kensal-Oakes in areal extent. The Luverne moraine was deposited during a minor readvance of the glacier after it had retreated from the Cooperstown position. This was the last readvance of ice in Barnes County.

Most of the Luverne drift sheet slopes toward the east and is drained by the Maple River and its tributaries. Most of the other drift sheets in the county are in the Sheyenne River drainage.

Physical characteristics.--The Luverne drift consists primarily of till. In Barnes County this till is composed of sandy to very clayey silt that is friable to cohesive and moderately calcareous. The oxidized till is grayish orange to yellowish gray, whereas the unoxidized till is olive gray. Size analyses of five samples indicate that the median size of the till of the Luverne drift is 0.020 mm, which is within the fine silt range (Block, 1965, p. 90). Cobbles and boulders are common inclusions within the Luverne drift. Generally crystalline rock types are most abundant, but, locally, shale pebbles and cobbles predominate. Block (1965, p. 50) reported that the till was coarser and boulders more numerous north of T. 141 N. The zone of oxidation in the Luverne drift has an average thickness of 22 feet. The maximum reported thickness of oxidation is 43 feet in 137-57-5aaa (Kelly, 1964b, p. 68).

All of the test holes drilled through the drift penetrated more than 100 feet of till and associated deposits; however, this sequence probably includes drift that is older than the Luverne deposits. Unfortunately, older units cannot be differentiated. Generally the drift is 60 to 80 feet thicker beneath the Luverne end moraine than beneath adjacent ground moraine to the east (pl. 3). The Kensal-Oakes drift has an average thickness of less than 50 feet and it probably underlies the Luverne drift. Consequently, the average thickness of the Luverne deposits probably exceeds 50 feet and may be more than 100 feet beneath the end moraine.

Most of the stratified drift landforms apparently were formed by streams of low competence, which precluded the transportation of gravel-size particles. The presence of abundant cobbles and boulders in the till indicates that these coarse clastics were present in the ice mass, but they are uncommon in the glaciofluvial deposits. Poorly sorted medium to coarse sand is the principal constituent of the outwash deposits associated with the Luverne drift. The ice-contact features consist primarily of poorly sorted sediments ranging in size from clay to gravel, but often include irregular masses of till.

Till landforms.--Three principal till landforms are associated with the Luverne drift sheet: end moraine, washboard moraine, and ground moraine (pl. 1).

The Luverne end moraine traverses Barnes County from north to south in R. 57 W., and locally it extends into R. 58 W. The width of the moraine ranges from less than 1 mile to more than 5 miles, but in most places it is slightly more than 2 miles. The central portion of the moraine in Barnes County is narrower than the northern and southern portions. This narrow part of the moraine is marked by a clearly defined axis, which, locally, is called the Alta Ridge. Elsewhere the end moraine is characterized by strongly rolling hills and numerous closed depressions (fig. 12) and has no apparent axis.

At the maximum advance of the Luverne glacier, the Sheyenne River was dammed by morainal debris in T. 138 N., R. 58 W., and a large lake (Lake Lanona) was formed to the north. Wave action in the lake planed off a large area adjacent to the moraine, and lake silts were deposited locally. This relatively flat plain clearly defines much of the distal edge of the moraine; elsewhere, the valley of the Sheyenne River marks the distal edge. The proximal boundary separating the Luverne end moraine from the associated ground moraine on the east is arbitrary. Generally the land surface slopes gradually toward the east from the end moraine, and there are few changes in landforms or in relief per unit area. Throughout much of its length, this end moraine-ground moraine boundary has

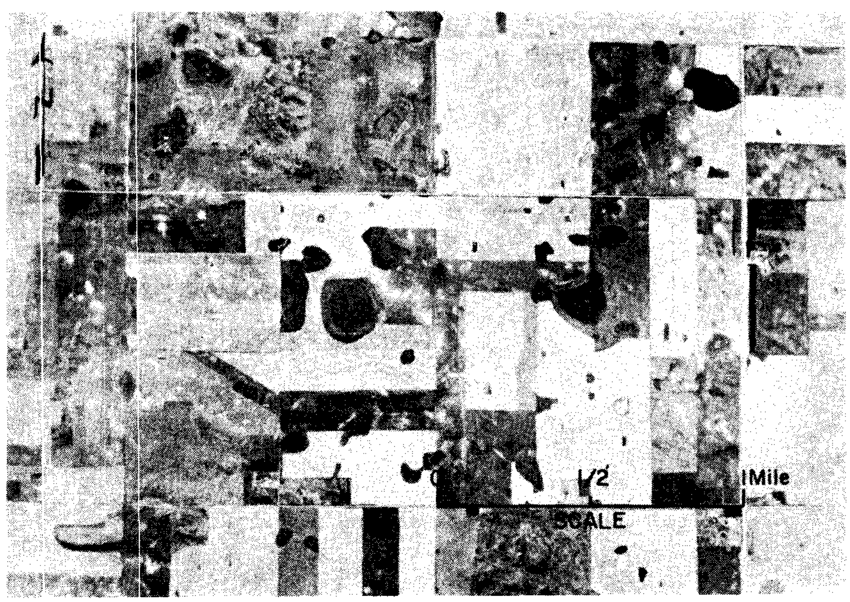

Figure 12. The large number of undrained depressions shown in the photograph are characteristic of the Luverne end moraine. (Sec. 4, 5, 8, 9, T. 142 N., R. 57 W.)

been mapped coincidental with the 1,400-foot contour.

An offset of the end moraine in T. 139 N., R. 57 W. indicates that two ice lobes were active in the area at the time the Luverne moraine was constructed. Although there was no significant interlobate reentrant as during Kensal-Oakes time, the southern lobe advanced approximately 3 miles farther west than the northern lobe. It was the southern lobe that blocked the Sheyenne River and created Lake Lanona.

About 80 square miles of the county are covered by washboard moraines. These features, which are most common in Tps. 138 and 139 N., R. 56 W., are convex toward the southwest and strike N. 40° W. (pl. 1). The orientation of the washboard moraines indicates that the Luverne ice mass receded toward the northeast. The crests generally are less than half a mile in length and rise 20 feet above the adjacent ground moraine. Characteristic of these landforms is the large amount of associated stratified sand. Commonly the crests are capped by sand and minor amounts of gravel, and the flanks generally have a thin veneer of stratified sand and gravel. Consequently, many of these moraines resemble ice-contact features. The large amount of stratified drift associated with the washboard moraines was deposited by melt water from the receding glacier. This melt water flowed south and east through numerous outwash channels.

Most of Barnes County east of the Luverne end moraine is blanketed by ground moraine that is characterized by gently to moderately rolling topography. Generally the relief on the Luverne ground moraine does not exceed 20 feet per mile, except where streams are entrenched. Although most of the streams are intermittent, the drainage is better integrated on this drift sheet than on the other drift sheets in the county, probably because the regional slope of the Luverne drift sheet is steeper than that of the other drift sheets. Most of the streams have extended their headwaters to the Luverne end moraine.

Stratified drift landforms.--Outwash channels, kames, a well-developed crevasse filling, and lake plains are the principal stratified drift landforms associated with the Luverne drift sheet.

Seven outwash channels traverse the Luverne ground moraine. The channels range from a quarter of a mile to a mile wide, and most are less than 30 feet deep. They probably originated as ice-marginal stream channels that carried melt water toward the southeast into the ancestral Maple River system. Inasmuch as the ice front receded toward the northeast, the channels in northern Barnes County are younger than those farther south. All of the channels are occupied, at least in part, by intermittent streams.

Although kames are scattered over much of the Luverne drift sheet, most of these features occur in groups of two or more in the vicinity of the end moraine. Generally the kames are less than a half a mile in circumference at the base and are less than 50 feet high.

A large ice-contact feature identified as a crevasse filling, extends from sec. 31, T. 142 N., R. 56 W. southward to sec. 24, T. 140 N., R. 57 W. This feature has many of the characteristics of an esker; however, the orientation parallel to the end moraine indicates that it probably is a crevasse filling. It consists of numerous sinuous ridges of sand and gravel having several short spurs that join the main ridge at near right angles. The crest of the ridge stands about 20 feet above the surrounding ground moraine. The overall length of the crevasse filling is more than 9 miles. This feature probably represents the accumulation of drift in a large fracture system that formed in stagnant ice. The lack of an associated melt-water channel, as well as the poor sorting of the material, indicates that little water was associated with formation of the crevasse filling.

Lake Lanona deposits.--During the advance of the glacier that deposited the

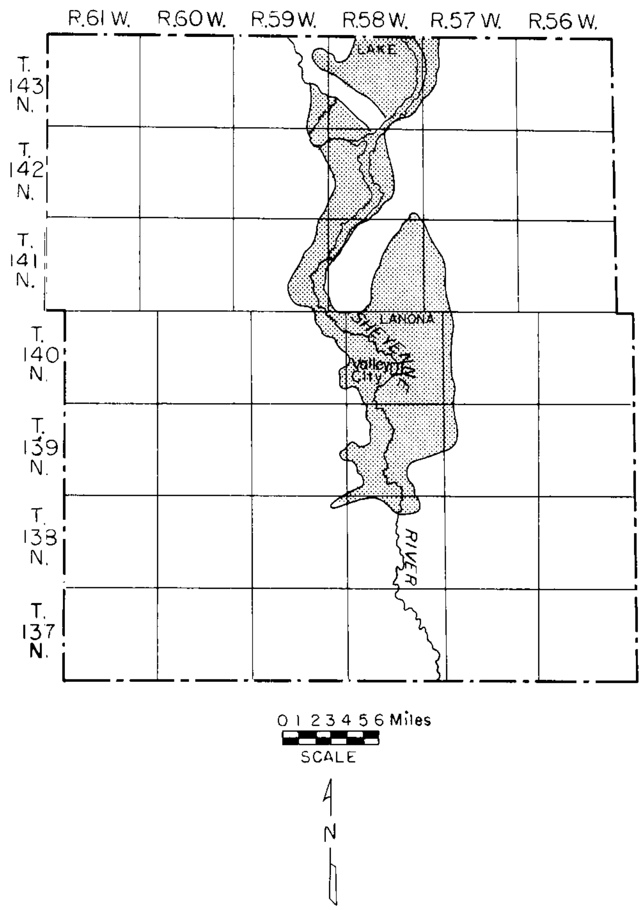

Figure 13. Areal extent of Lake Lanona.

Luverne moraine, the ancestral Sheyenne River was a proglacial melt-water stream, eroded at a level of approximately 90 feet above the present Sheyenne flood plain. When the Luverne ice reached its maximum extent, the ancestral Sheyenne River was blocked, and a large, shallow lake was created (fig. 13). Silt and clay accumulated in the deeper parts of the lake, elsewhere the inundated ground moraine was planed off by wave action. Willard (1909, p. 4) was the first to describe this lake bed, and he applied the name Lanona Plain. The type area was in the vicinity of Lanona, a community formerly located in sec. 31, T. 140 N., R. 57 W., about 3 miles southeast of Valley City.

At its maximum extent, Lake Lanona covered about 160 square miles. The lake extended northward from the ice and drift dam in T. 138 N., R. 50 W. into Griggs County, and its maximum width exceeded 10 miles in T. 141 N. Lake Lanona had two outlets: one was through the ice and drift dam and down the Sheyenne channel, and the other was through the Stoney Slough. The elevations of these outlets were about 1,410 feet. The maximum depth of the lake was approximately 60 feet, although the average depth was probably less than 20 feet.

The deposits that accumulated in Lake Lanona consist primarily of yellowish-gray to dusky-yellow, well-sorted, laminated, calcareous silt and clay (fig. 14). Locally, the bedding is graded, and much of the silt displays minute crossbedding. Thin, discontinuous sand beds are present in most exposures, but generally com-

Figure 14. Lake Lanona sediments generally are well-sorted silt and clay that are thin bedded to massive. Moderate dip angles were produced by slumpage on the lake floor.

prise only a small part of the total thickness of an exposure. Locally, fine to coarse, cross-bedded sand and fine gravel grade horizontally into lacustrine silt and clay. The coarse sediments were deposited by tributary streams that drained into Lake Lanona. One such stream deposit in the S1/2 of sec. 25, T. 142 N., R. 58 W. contains numerous gastropods and fragmental pelecypods, although the lacustrine deposits generally are barren of fossils. The present areal distribution of the lake deposits is shown in plate 1.

The thickness of the deposits that accumulated in the lake is rather variable because of the irregularity of the topography. The greatest thicknesses accumulated in the drowned river valley, whereas only a thin veneer of sediments accumulated on the inundated ground moraine. Maximum thickness of the lake sediments is about 30 feet, although, locally, as much as 60 feet are exposed on the valley walls. This is an anomalous thickness inasmuch as the sediments were deposited on the ancestral Sheyenne valley walls and actually represent a thin veneer.

Except where entrenched by the Sheyenne River valley, the topography of the Lanona Plain is nearly flat to gently rolling. Maximum relief is about 20 feet per mile, but generally it is about 10 feet per mile. When the lake was at maximum pool, several islands stood as much as 50 feet above lake level. Most of these were kames on the ground moraine.

ALLUVIAL DEPOSITS

The youngest sediments in Barnes County were deposited in stream channels after withdrawal of the glaciers from the area, that is, during the Recent Epoch. These deposits are restricted to the flood plains of the Sheyenne River valley and a small stream in T. 137 N., Rs. 58 and 59 W. (pl. 1).

Fine-grained deposits of silt and clay are the principal lithologies of the alluvium. In the Valley City area, yellowish-brown to brown, silty to sandy clay is present at the surface and is underlain by similar deposits that are gray in color. Thin lenses of fine to coarse sand are present locally. Lignite fragments are dispersed throughout the alluvium. Fossils are abundant locally; gastropods are most common, but numerous small pelecypods are present at some sites.

The thickness of the alluvial deposits ranges from 0 to 49 feet in test holes drilled at Valley City. More than 40 feet of alluvium was penetrated by borings made by the Bureau of Reclamation in T. 138 N., R. 58 W. Usually the alluvium is thickest near the center of the valley and pinches out along the edges. There appears to be no relationship between the thickness of the alluvium and the present position of the Sheyenne River itself.

Alluvium was deposited in the Sheyenne valley as valley fill and was subsequently dissected by the river. Consequently, the only landforms associated with the alluvial deposits are poorly developed terraces approximately 10 feet above the present level of the Sheyenne River. These terraces are restricted to the river valley south of Kathryn.

GEOLOGIC HISTORY

The Williston Basin had a complex history during the Paleozoic and Mesozoic Eras. Near the center of the basin more than 10,000 feet of Paleozoic and Mesozoic rocks accumulated, but these strata thin away from the center. Barnes County, which is located near the eastern edge of the basin, is underlain by more than 2,400 feet of sedimentary rocks (Nelson, 1955). The detailed geologic history of these units has been given by Ballard (1963), Hansen (1955), and Gill and Cobbin (1965); and will not be discussed here.

During most of the Cenozoic Era, the surface of Barnes County was exposed to weathering and erosion. Northeastward-flowing streams crossed the area, and the surface probably was characterized by a moderately rolling, well drained topography (pl. 4, A, in pocket).

Prior to the advance of the first glacier into the area, the Spiritwood channel was eroded. There are three plausible explanations for the origin of the channel. Most of the evidence indicates that it was eroded by a major stream that had been blocked and diverted by an advancing glacier. Lemke and Colton (1958, fig. 2) have shown that the ancestral Knife River extended as far east as Sheridan County, and the ancestral Cannonball River is known to have traversed Wells County (Frank Buturla, Jr., oral communication). It is possible that during the first glacial advance, these two rivers were blocked and diverted through the Devils Lake diversion channel (Paulson and Akin, 1964, fig. 9) and southward through the Spiritwood channel (fig. 15, stage 1).

A second plausible explanation for the origin of the Spiritwood channel is that it was eroded as a melt-water channel during the first ice advance and is totally unrelated to the preglacial drainage. This theory is supported by the presence of vast outwash deposits that thicken northward, as well as by the southward gradient. The fact that nearly all of the tributaries are on the west side of the channel indicates that it may have been an ice marginal channel with the glacier confining it on the east. However, the dimensions of the channel are not compatible with this theory. The average width of the channel is 6 miles, and it is unlikely that an advancing glacier would have sufficient melt water to produce a channel of that width. Moreover, the Spiritwood channel generally is eroded more than 250 feet into the Cretaceous shale. An appreciable period of time would be required to erode a channel to that depth, and outwash channels probably were utilized for relatively short periods of time.

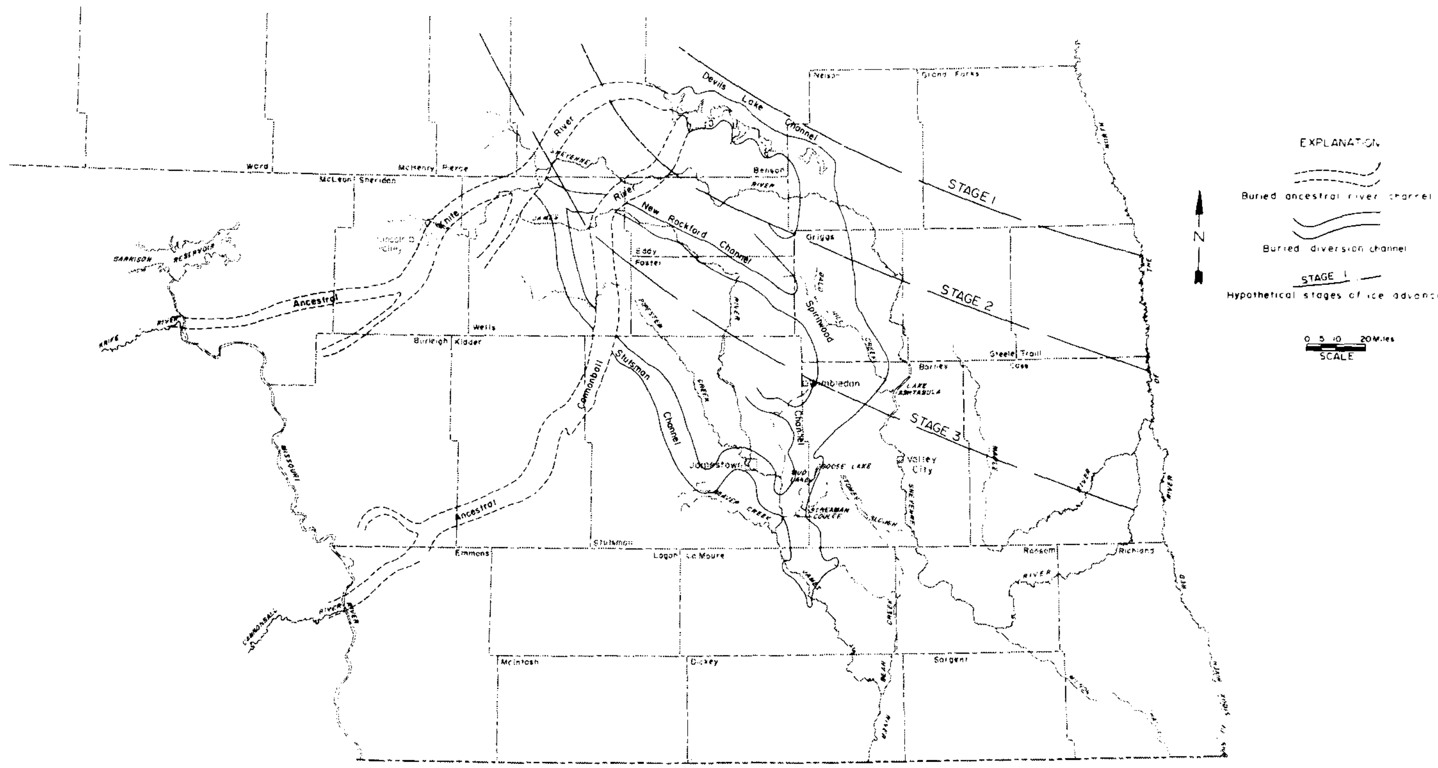

Figure 15. Elements of the inferred prediversion drainage systems and present drainage systems of southeastern North Dakota.

The third theory of origin was proposed by Huxel (1961b, p. 180); he suggested that the Spiritwood channel complex was part of the ancestral Cheyenne drainage system of South Dakota. Flint (1955, p. 148) had proposed that this drainage system entered North Dakota south of Barnes County and continued northward into the Hudson Bay area. The fact that the Spiritwood channel becomes wider toward the north supports Huzel's theory. However, the southward gradient, lack of alluvium, and the angle at which tributaries join the channel cannot be explained by this theory.

Regardless of the actual mode of development of the Spiritwood channel, it was one of the major proglacial drainage systems in the area. As the first glaciers advanced over Barnes County, outwash accumulated in the channel, and it was buried by glacial drift. This first glacial advance, which is dated as Iowan (?) by Lemke and Colton (1958, p. 46), extended beyond the Missouri River, leaving Barnes County blanketed by a thick accumulation of ice of the Des Moines lobe. After reaching its maximum extent, the ice began a recession that was characterized by numerous stillstands and readvances of the ice front. It was during the late Wisconsin glacial retreat that the landforms of Barnes County were formed.

The Millarton ground moraine was uncovered as the margin of the ice sheet receded toward the north. Short pauses in this retreat resulted in the development of isolated moraines in T. 137 N., R. 61 W. At this time the major drainage from the ice was across southern Stutsman County to the James River (Winters, 1963, p. 50).

The origin of the channel by the diversion and erosion of these streams is supported by several lines of evidence. In Barnes County the gradient of the Spiritwood channel is 3 feet per mile toward the south, similar to other existing streams in the State. Width of the Spiritwood channel is compatible with those of the ancestral Knife and Cannonball, assuming additional water would have been contributed by the glacier that diverted the streams. The angle at which tributaries join the Spiritwood indicates that the parent stream flowed southward (Kelly, 1964a, fig. 1). Only glacial outwash was penetrated by test drilling in the Spiritwood channel. The Knife and Cannonball Rivers probably had a very low competence and were capable of transporting only fine sand, silt, and clay. However, at the point where diversion occurred, additional water and large quantities of outwash would have been picked up. This would explain the thick deposits of outwash in the Spiritwood channel. This is also supported by the fact that the outwash deposits thicken northward (Kelly, 1964a, fig. 2).

As the glacial front advanced, the Devils Lake diversion channel was overridden and the Knife and Cannonball Rivers were diverted southeastward. A deep, narrow channel was eroded across Eddy and Foster Counties and joined the Spiritwood channel in southwestern Griggs County (fig. 15, stage 2). This diversion channel was called the Heimdal channel by Huxel (1961b, p. 180), but was renamed the New Rockford channel (Henry Trapp, Jr., oral communication). Further advance of the glacial front (fig. 15 stage 3) resulted in diversion of the Cannonball River through the Stutsman diversion channel to the lower Spiritwood channel.

When the ice reached the vicinity of Eldridge (fig. 8), the ice margin was sufficiently immobile to allow the accumulation of the Eldridge end moraine. Thus, the moraine is a recessional feature and does not define the terminal position of a readvance of the ice sheet. Beaver Creek and the James River in Stutsman County continued to act as the major drainage system (fig. 15); however, some of the melt water flowed southward through the unnamed channel in T. 137 N., R. 60 W. and into Bear Creek in Ransom and LaMoure Counties before emptying into the James River. The ice receded northward approximately 10 miles before it again paused. During this stillstand of the ice, the well-defined Eldridge recessional moraine was formed, and part of the melt water flowed southwestward to the James River through Streaman Coulee.

The position of the Buchanan drift in Barnes County can only be inferred, owing to subsequent burial of this unit beneath the Kensal-Oakes drift sheet. Consequently, very little is known of the events immediately following deposition of the Eldridge recessional moraine. The inferred position of the Buchanan deposits (fig. 8) indicates that the ice retreated northward. Winters (1963, p. 58) stated that, in the type area, the Buchanan moraine "is probably a recessional feature formed at the margin of a shrinking ice sheet that had previously formed the Eldridge and Millarton moraines." This conforms with the rather meager amount of information that is available from Barnes County.

During the time that ice was retreating northward from the western part of the county, eastern Barnes and adjacent counties remained blanketed beneath the glacier. However, shortly after the Buchanan drift was deposited, there were significant readvances of ice from the north and east. The Kensal-Oakes end moraine and associated landforms were produced at the edge of the lobated ice margin. During the advance, flutings were eroded that revealed two slightly different directions of movement, although the general movement was toward the southwest. The Wimbledon esker complex was deposited at this time, and in the interlobate area, numerous ice-contact features were formed.

All of the drainage from the Kensal-Oakes ice emptied into the James River. The melt-water channels in the Wimbledon area drained westward into Sevenmile Coulee, Pipestem Creek, and into the James River (Winters, 1963, p. 73). The melt-water channel now occupied by Goose and Mud Lakes, T. 138 N., R. 61 W., drained southwestward into Streaman Coulee and ultimately into the James River (fig. 15). Water from the interlobate area of the glacier flowed through several channels, all of which coalesced in T. 138 N., R. 60 W., and formed the Stoney Slough drainage system. The melt water flowed southward through Bear

Creek and emptied into the James River in eastern Dickey County. All of these channels were abandoned when the Kensal-Oakes ice retreated northeastward.

A pause in the recession of the ice front occurred about 20 miles northeast of the Kensal-Oakes position, and the Cooperstown end moraine was deposited. This was of relatively short duration, as shown by the low, discontinuous character of the moraine.

Bald Hill Creek was formed as an ice-marginal melt-water channel, which drained toward the south. The area north of the present confluence of Bald Hill Creek with the Sheyenne River (Lake Ashtabula) was blanketed by ice. Consequently, the creek flowed south eroding the channel now occupied by the Sheyenne River on the distal side of the Kensal-Oakes end moraine (pl. 4, B). In northwestern Ransom County, the stream continued southward, ultimately emptying into the James River (fig. 15). The highest terraces along the present Sheyenne River in Barnes County are remnants of this initial flood plain formed during the Cooperstown ice advance (fig. 16). Withdrawal of the Cooperstown ice front was accompanied by downcutting of Bald Hill Creek and the ancestral Sheyenne River to a level approximately 70 feet below the upper terrace.

The amount of Cooperstown withdrawal is problematical owing to a subsequent glacial readvance that buried much of the Cooperstown drift. At the maximum readvance of the ice, the Luverne end moraine and associated deposits were formed, and a large melt-water channel joined Bald Hill Creek in T. 142 N., R. 58 W., forming the headwaters of the Sheyenne River as it exists today. Lake

Figure 16. Sand and gravel terrace deposits of the Sheyenne River overlying the marl unit of the Pierre Formation (sec. 28, T. 140 N., R. 58 W.).

Lanona was ponded behind the dam of ice and glacial drift (pl. 4, C), and much of central Barnes County was inundated.

In the vicinity of Fort Ransom, about 6 miles south of the Barnes county line, the Luverne ice front turned southeastward. When Lake Lanona overflowed, the Sheyenne River again acted as the principal melt-water channel (pl. 4, D). However, with the recession of ice, a lower outlet to the southeast became available to the Sheyenne. Consequently, the river abandoned its channel south of Fort Ransom to the James River, and was diverted southeastward, ultimately emptying into the Minnesota River through the Milnor channel (Baker, 1966, p. 79).

The Luverne ice front gradually retreated northeastward, slowly uncovering the large area of Luverne ground moraine and washboard moraine. This was the final recession of the ice sheet from Barnes County. Meltwater from the waning ice eroded numerous channels that formed the Maple River system, which emptied into the ancestral Sheyenne River in northcentral Ransom County (fig. 15). A gravel-capped flood plain developed in the Sheyenne valley during the time that the stream discharged through the Milnor channel. This was the third flood plain formed by the Sheyenne; the northern part of Valley City is built on a terrace remnant of this former flood plain.

Lake Agassiz began to form in Cass and Richland Counties as ice retreated from the Luverne position. The lake served as a lower outlet to streams from the west; consequently, the Sheyenne River was diverted from its course down the Milnor channel and into the lake. Lake Agassiz existed for sufficient time to allow the Sheyenne to erode a narrow flood plain. Remnants of this former flood plain are preserved as terraces about 10 feet above the present river level south of the town of Kathryn. When Lake Agassiz drained, the Sheyenne emptied into the Red River of the North and established the drainage as it exists today. Since the lake was drained, the river has incised its channel (pl. 4, E).

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