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

BULLETIN 41

North Dakota State
Water Conservation Commission
MILO W. HOISVEEN, *State Engineer*

COUNTY GROUND WATER STUDIES 2

GEOLOGY AND GROUND WATER RESOURCES

of Stutsman County, North Dakota

Part I - GEOLOGY

By

HAROLD A. WINTERS

GRAND FORKS, NORTH DAKOTA
1963

This is one of a series of county reports which will be published cooperatively by the North Dakota Geological Survey and the North Dakota State Water Conservation Commission in three parts. Part I is concerned with geology, Part II, basic data which includes information on existing wells and test drilling, and Part III which will be a study of hydrology in the county. Parts II and III will be published later and will be distributed as soon as possible.

CONTENTS

CONTENTS, Continued

CONTENTS, Continued

ILLUSTRATIONS

(Plates are in pocket)

ILLUSTRATIONS, Continued

TABLES

GEOLOGY AND GROUND WATER RESOURCES OF STUTSMAN COUNTY, NORTH DAKOTA

Part 1 Geology

By HAROLD A. WINTERS

ABSTRACT

Stutsman County, in south-central North Dakota, comprises about 2,300 square miles. The west part of the county is within the Coteau du Missouri, a part of the Missouri Plateau section of the Great Plains physiographic province. The east part of the county is within the Drift Prairie section of the Interior Lowlands province. The Missouri Escarpment trends south through the center of the county and forms the boundary between these two areas. The highest altitude is in the west part of the county and exceeds 2,000 feet above sea level. The lowest point is in the James River valley in the southeast part of the county at an altitude of about 1,340 feet above sea level.

Glacial drift overlies the bedrock in most of the county. Rocks of the Late Cretaceous age directly underlie the glacial drift. Older Cretaceous, Jurassic, Mississippian, Devonian, Silurian, Ordovician and possibly Cambrian rocks also are present in the subsurface. The surface of the Precambrian basement rocks decreases in altitude to the west-northwest.

Late Cretaceous rocks that directly underlie the glacial drift include the Niobrara Shale, Pierre Shale, and Fox Hills Sandstone. The Niobrara Shale which consists of a medium-gray shale, does not crop out in the county but has been identified as underlying glacial drift in the lower part of a deep bedrock valley that is filled with drift. The Pierre Shale underlies glacial drift in most of the county and is the only bedrock that crops out in the area. The formation consists of a dark-gray to black, highly jointed shale that weathers readily into small chips. The Fox Hills Sandstone consists of fine to medium-grained sandstone that may be interbedded with siltstone and shale. This formation is not exposed but it directly underlies glacial drift in the southwest part of the county in a bedrock high.

The bedrock surface underlying the glacial drift is characterized by considerable relief. Several isolated bedrock highs that exceed 1,600 feet above sea level are in the west part of the county, but a well-defined east-facing bedrock escarpment in the area of the Missouri Escarpment does not exist. Much of the bedrock is at an altitude of 1,400 to 1,500 feet above sea level, but this surface is interrupted by valleys that have been eroded into the bedrock. The largest of these bedrock valleys includes the possible continuation of the ancestral Cannonball River valley and a large valley, referred to as the Spiritwood Valley, that trends north along the east boundary of the county and that probably existed prior to glaciation. In the present-day topography there is no direct reflection of the bedrock surface.

Glacial till and glaciofluvial material are the most abundant surficial Pleistocene deposits in the county. Other surficial deposits include proglacial and postglacial lacustrine sediments, colluvium, recent alluvium, and some wind-blown material. There is little variation in the physicial characteristics of the surficial till. The surficial till consists largely of material finer than coarse sand, in which silt and clay are abundant. The average depth of oxidation is about 20 feet and a leached zone is absent Stone counts reveal no major variation in the types of pebbles that occur within the till. Grain-size analyses of fifty till samples indicate that surficial till is everywhere similiar, though there is a tendency for clay and

silt to be more abundant in samples from the west part of the county and a slightly larger amount of sand and granules occur in samples from the northeast part of the county.

The glacial drift is thickest in the west part of the county and in areas where bedrock valleys are present. Subsurface data indicate that the higher altitude of the topography in the west part of the county is due mainly to the deposition of large amounts of drift rather than due to bedrock conditions. The average thickness of drift in the east part of the county is much less than that in the west, but in the east, where bedrock valleys are present, the drift may exceed 500 feet in thickness. The age of the drift in the subsurface is questionable, but stratigraphic relationships, the occurrence of cemented drift and oxidized zones in the subsurface, and one radiocarbon date on wood fragments from the subsurface indicate that early Wisconsin or pre-Wisconsin drift probably exists within the area.

Two distinctly different groups of glacial landforms occur within the county; these may be subdivided into morpho-stratigraphic units. The first is in the Coteau du Missouri and resulted mainly from a glacier that was characterized by extensive stagnation. The second is in the Drift Prairie and was formed in association with a glacier that possessed a margin which retreated in an orderly manner and which occasionally halted or readvanced. Landforms within the Coteau du Missouri include the Streeter end moraine and various forms resulting from stagnation of the ice, including hummocky stagnation moraine, perched lacustrine plains, a large pitted outwash plain, ice-restricted outwash plains, and an ice-walled gravel train. The Streeter moraine was formed at the margin of an active ice sheet, and a radiocarbon date indicates that the time of formation was prior to 11,070±300 years ago. The stagnation landforms were, at least in part, in the process of formation at the time of the radiocarbon date mentioned above. The occurrence of carbonaceous material and pelecypod shells within ice-contact glaciofluvial sediments indicates that some forms of life existed in the stagnant-ice environment.

Major landforms within the Drift Prairie include the Millarton, Eldridge, and Buchanan end moraines in the south-east and east-central part of the county. These moraines were formed during halts or minor readvances of the ice margin as it retreated north from the east part of the county. The Grace City end moraine, in the north-central part of the area, may have formed as a recessional feature shortly after the Buchanan moraine was deposited, or it may have formed contemporaneously with the Kensal end moraine, in the northeast part of the county, which was deposited by a significant readvance of the ice sheet. Extensive areas of ground moraine also occur in the east part of the county. Local recessional features, referred to as washboard moraines, are common within some areas of ground moraine, and their trends record, at least in part, the configuration of the ice margin at the time they were formed.

The Millarton, Eldridge, and Buchanan moraines and their associated landforms were deposited after the Streeter moraine but before the Kensal moraine. The Kensal moraine was probably formed prior to 10,050±300 years ago.

The preglacial streams of the area probably drained north rather than south as they do today. Little is known of the drainage conditions that existed after the area was first glaciated and prior to the final disappearance of the ice, but the character of the drift in the subsurface suggests that the pre-existing drainageways have been diverted, obstructed, and buried as a result of subsequent glaciation. Presently the west part of the county lacks an integrated drainage system and major melt-water channels are absent. This indicates that large amounts of melt-water were not available during the last stages of ice stagnation. As a result, this part of the county is characterized by youthful drainage, and lakes and marshes are common. In the east part of the county, however, several large melt-water channels formed as the ice margin retreated from a position marked by the Millarton, Eldridge, and Buchanan moraines. The drainageways include Minneapolis Flats at the foot of the Missouri Escarpment, Beaver Creek valley in the south-east part of the county, the part of the James River valley south of Jamestown, Pipestem Creek valley in the north-central part of the county, and a forerunner to Sevenmile Coulee in the east part of the county. Furthermore, two major drainage diversions developed at the time the ice readvanced to form the Kensal moraine. These resulted in the formation of the part of the James River valley north of Jamestown and in the present course of Sevenmile Coulee. No major changes in the drainage system have developed since the ice margin last retreated from the county.

Terraces exist within some of the former melt-water channels, and one group is conspicuous in the lower James-Pipestem system. These low terraces represent remnants of a former valley train that was deposited after the ice margin retreated from a position marked by the Eldridge moraine, and that was dissected prior to the time that Pipestem Creek valley ceased to be active as a melt-water channel. Low terraces also are present within Sevenmile Coulee, and some of these are interpreted as kame terraces which were formed during the last ice advance that reached the northeast part of the county.

INTRODUCTION

This report describes certain aspects of the geology of Stutsman County, in the southeast part of North Dakota. The study is based on findings from a project sponsored by the North Dakota Geological Survey, the North Dakota State Water Conservation Commission, and the Ground Water Branch of the Water Resources Division of the United States Geological Survey. The major objectives of this report are as follows: 1) To present a general description of the character and attitude of the bedrock in the county, with emphasis on the rock formations that directly underlie the glacial drift; 2) to describe the character and occurrence of glacial landforms and glacial drift within the county; and 3) to set forth an interpretation of the glacial history of the area.

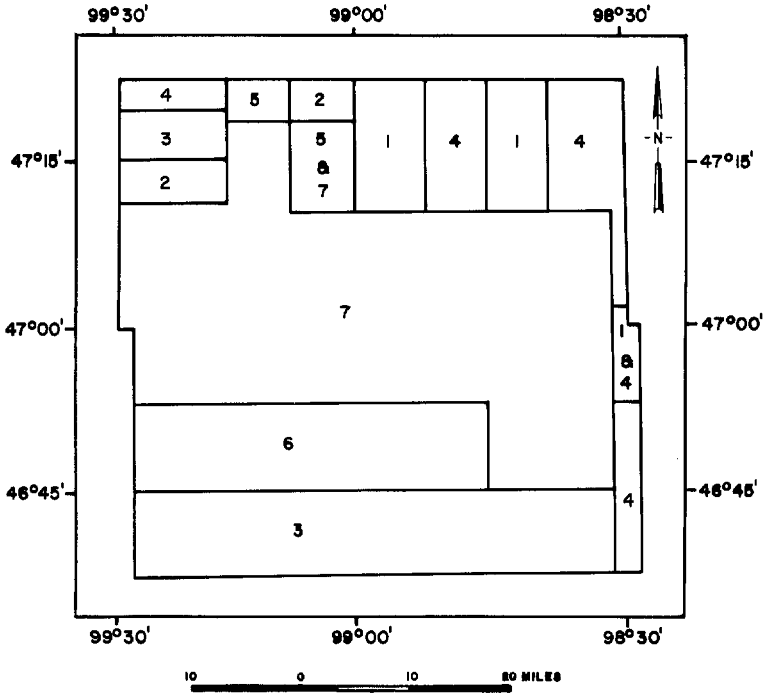
This report will provide a better understanding of the geology of North Dakota and may be useful in the search for and utilization of ground water and sand and gravel deposits.

Most of the county was mapped on U. S. Geological Survey topographic quadrangles at a scale of 1:24,000. In areas not covered by these maps, aerial photographs and base maps at a scale of 1:62,500 were used, and altitudes were determined with the aid of an altimeter. An attempt was made to examine each section within the 64 townships in the county by mapping along section lines and investigating critical areas within the section. Natural and man-made exposures of the surficial material were examined, and where these were not abundant, auger holes were dug to determine the character of the sediments. Much of the information on subsurface glacial drift was obtained from logs of test holes completed under the direction of the Ground Water Branch of the U. S. Geological Survey in cooperation with the North Dakota State Water Conservation Commission and the North Dakota Geological Survey. Additional information was obtained from water well-inventory data provided by the U. S. Geological Survey. Samples of bedrock, glacial drift, and material suitable for radiocarbon dating were collected in the field for laboratory analyses.

Geologic names used herein conform to the usage followed by the North Dakota Geological Survey rather than that of the U. S. Geological Survey.

ACKNOWLEDGMENTS

The county was mapped during field seasons from 1958 through 1960. The writer started mapping during the summer and fall of 1958. During the summer of 1959 the writer was assisted by Mark Rich, North Dakota Geological Survey, and C. J. Huxel, Jr., Ground Water Branch, U. S. Geological Survey. In the summer of 1960 D. E. Hansen, Miller Hansen, and Jack Kume, North Dakota Geological Survey, and C. J. Huxel, Jr. and P. G. Randich, U. S. Geological Survey, assisted the writer in the mapping. Each man was assigned parts of the county to map and their findings are integrated into this report (fig. 1). C. J. Huxel, Jr. and Jack Kume made the size analyses of the glacial till samples in 1961.



Map of Stutsman County Showing Areas Mapped by Various Participants

1. D. Hansen
2. M. Hansen
3. C. Huxel
4. J. Kume
5. P. Randich
6. M. Rich
7. H. Winters

FIGURE I

The writer wishes especially to express his appreciation to the men named above for their cooperation and initiative. Without their participation this report would not have been possible at this time. C. J. Huxel, Jr. deserves particular credit for his continued cooperation and interest in this study.

Special appreciation is due Wilson M. Laird, State Geologist of North Dakota, the late J. W. Brookhart and Edward Bradley, former and present district geologists, U. S. Geological Survey. Valuable professional criticism and administrative assistance were obtained from these men.

The writer is indebted to R. B. Colton and R. W. Lemke for the loan of aerial photographs of the county during the winter and spring of 1959 and for the loan of 1:125,000 glacial map of Stutsman County (unpublished); to R. W. Lemke for the forwarding of material submitted by C. J. Huxel, Jr. and the writer to the U. S. Geological Survey for radiocarbon analysis; to the Ground Water Branch of the Water Resources Division of the U. S. Geological Survey for the use of water well-inventory data and test boring data; and finally to the people of Stutsman County who cooperated so well in many ways with the participants in this study.

PREVIOUS WORK

Glacial deposits within Stutsman County were first described by T. C. Chamberlin in 1883 (p. 393-400) in a report of the "Terminal Moraine of the Second Glacial Epoch." Chamberlin briefly described the landscape in the west part of the county.

In 1896 J. E. Todd (p. 13-59) made a study of "The Moraine of the Missouri Coteau and Their Attendant Deposits." His investigation deals in part with Stutsman County though the emphasis is on the landforms in the west part of the county.

D. E. Willard reported in 1909 on the geology of the Jamestown, Eckelson and Tower quadrangles. A part of this study was concerned with the southeast quarter of the county. Willard's map, at a scale of 1:125,000, shows some of the morainal tracts and bodies of outwash mentioned in this report.

Q. F. Paulson (1952) described a small part of extreme southwest Stutsman County in a report on the geology and occurrence of ground water in the vicinity of Streeter, North Dakota.

In 1955 R. J. Kresl reported on the "Geology of the Eldridge Quadrangle" and in 1956 enlarged upon this study in a paper on the "Geology of the Lower Pipestem Creek Area," which describes an area of about 200 square miles near the center of the county.

F. D. Holland (1957) briefly described some of the aspects of the geology in a field trip guidebook of the Jamestown area.

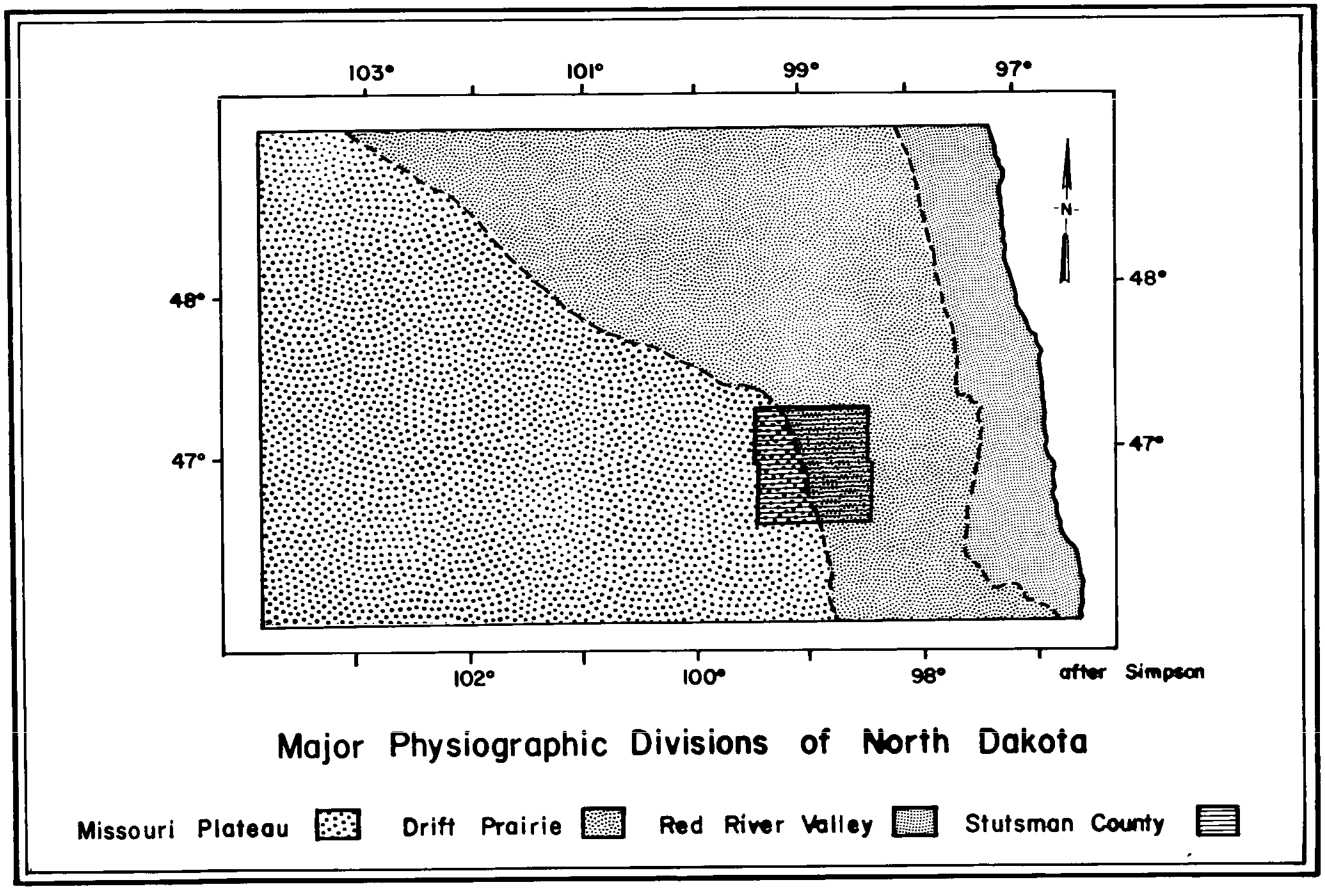
In 1958 R. W. Lemke and R. B. Colton prepared a "Summary of the Pleistocene Geology of North Dakota." This report includes some description of glacial landforms in the county. In addition, these writers have prepared a map of the glacial geology of North Dakota (in press). The part of this map at 1:125,000 covering Stutsman County was sent to the author.

After completing the field work for this report, the writer (Winters, 1961) described certain landforms that occur within the county but the paper dealt with the character of the landforms rather than with a specific area within the county.

GEOGRAPHY

TOPOGRAPHY AND DRAINAGE

Stutsman County is in the south-central part of North Dakota and includes 64 townships which form a 48 by 48 mile square that covers about 2,300 square miles (fig. 2). The west part of the county, a relatively high area of rugged morainal topography, is within that part of the Missouri Plateau known as the



Major Physiographic Divisions of North Dakota

FIGURE 2

Coteau du Missouri. The east part of the county is within the Drift Prairie, which may be described as a youthful glaciated plain that is interrupted by end moraines and stream valleys. The boundary between these two major physiographic divisions consists of a sloping surface that decreases about 200 to 400 feet in altitude to the east within a horizontal distance of 2 to 8 miles. This feature, known as the Missouri Escarpment, trends north-northwest through the central part of the county. The maximum relief in the county exceeds 600 feet.

Lakes and marshes are abundant in the west part of the county, but an integrated drainage pattern is absent. Chase Lake, northwest of Medina, is the largest body of water in this area and is more than 2 miles in length. Most of the lakes and marshes are in what are locally called "potholes" and are generally less than a mile in length. During periods of prolonged dryness they may be reduced in size or may dry up completely.

In the east part of the county lakes and marshes are also common. The larger lakes, such as Spiritwood and Blue Lakes, generally are within former glacial melt-water channels in which drainage is obstructed by glacial drift or man-made structures.

Several large valleys, occupied by underfit streams, are in the east part of the county. The major stream is the James River, which rises near the geographic center of the state, flows south through the east part of Stutsman County, and eventually joins the Missouri River. A dam has been constructed across the stream course north of Jamestown and impounds a large reservoir with a surface altitude about 1,430 feet above sea level. Farther upstream other man-made structures have resulted in the formation of Arrowwood and Jim Lakes within the valley of the James River.

A second large valley contains Pipestem Creek, which rises to the northwest in Wells County, flows southeast through the north-central part of Stutsman County, and joins the James River near Jamestown. Other smaller valleys include Beaver Creek and unnamed intermittent streams that occupy Minneapolis Flats, Sevenmile Coulee and Streaman Coulee.

CLIMATE

The climate of Stutsman County is sub-humid and continental. The county, bisected by the 47° parallel, is about 100 miles southeast of the geographical center of North America. This continental location results in warm summers and cold winters. The maximum precipitation occurs during the summers, and the winters are usually dry. In addition, the county is in the mid-latitudes, where cyclones and anticyclones may produce significant variations in the weather within short periods of time. Large annual temperature ranges are associated with the continental climate. The mean monthly temperatures for January and July are 7.3° and 69.0° F., respectively, as recorded at the Jamestown Airport, and 8.1° F. and 71.9° F., respectively, as recorded at the Jamestown Hospital (U. S. Dept. of Commerce, 1955, p. 34); thus the average annual temperature range is 61.7° F. and 63.8°F, at these two recording stations. Temperatures greater than 90° F. are not uncommon in the summer, and sub-zero cold waves are frequent in the winter. The highest and lowest temperatures recorded at the Jamestown Hospital were 118° F. and —42°F. (U. S. Dept. of Commerce, 1955, p. 37). Thus the maximum temperature range at this location is 160° F.

During the winter the temperatures may be low enough to halt stream flow by freezing. The summers are comparatively short, but the total number of sun hours is relatively high. This is the result of long, consecutive periods of daylight and numerous cloudless days. About 16 hours of daylight occur on or about the time of the summer solstice. Table 1 presents a summary of the monthly and annual temperature regimes of two recording stations in the area. Two weather stations in the county have recorded an average annual precipitation of 18.71 inches

TABLE 1. — Temperature and precipitation recorded in Stutsman County

JAMESTOWN AIRPORT

Month	Total Precipitation	Mean Snowfall	Mean Temp.	Temp. Mean Max.	Temp. Mean Min.	High Temp.	Low Temp.
Jan.	.78"	8.4"	7.3°	17.4°	2.9°	53°	—36°
Feb.	.60	6.8	10.7	20.9	0.4	44	—32
Mar.	1.05	9.3	23.1	32.5	13.7	80	—29
Apr.	1.35	3.1	41.8	53.6	30.1	94	— 5
May	2.14	1.0	52.9	66.0	39.8	95	12
June	3.07	t	62.0	74.2	49.7	98	30
July	2.74	t	69.0	82.3	55.7	104	35
Aug.	2.59	t	67.2	81.1	53.3	105	35
Sept.	1.75	.2	57.1	70.7	43.5	100	18
Oct.	1.31	1.1	46.0	59.3	32.7	87	6
Nov.	.70	4.7	26.7	36.2	17.2	69	—17
Dec.	.63	6.9	12.9	22.9	2.9	61	—30
Mean Ann.	18.71	41.5	39.7	51.4	28.0		

JAMESTOWN STATE HOSPITAL

Month	Total Precipitation	Mean Snowfall	Mean Temp.	Mean Max. Temp.	Mean Min. Temp.	High Temp.	Low Temp.
Jan.	.48"	5.7"	8.1°	18.0°	1.9°	51°	—36°
Feb.	.61	6.7	11.3	21.3	1.4	58	—42
Mar.	.91	7.8	25.0	34.7	15.3	80	—29
Apr.	1.63	3.6	42.1	54.1	30.2	95	— 2
May	2.06	.6	55.3	68.6	41.9	107	12
June	3.07	.0	64.6	77.2	51.9	107	30
July	2.60	t	71.9	85.8	57.9	118	35
Aug.	2.19	t	68.9	83.0	54.9	107	32
Sept.	1.29	.1	58.5	72.6	44.5	107	19
Oct.	1.28	1.2	46.1	58.8	33.4	90	0
Nov.	.71	5.7	27.8	37.5	18.1	72	—14
Dec.	.52	6.0	14.8	24.4	5.2	67	—32
Mean Ann.	17.35	37.4	41.2	53.0	29.4		

SOURCE: *Climatic Summary of the U. S. for 1931 through 1952* (Washington, D. C.: U. S. Dept. of Commerce, 1955), p. 15, 33, 34, and 37.

and 17.35 inches (U. S. Dept. of Commerce, 1955, p. 15). Significant variations from the average occur both from year to year and between stations for the same year. Only 6.91 inches of precipitation were received at the Jamestown Hospital in 1935, while 25.84 inches of precipitation were recorded at the Jamestown Airport in 1950. For the same year, 1950, 18.34 inches of precipitation fell at the Jamestown State Hospital, about 3 miles south of the airport (U. S. Dept. of Commerce, 1955, p. 15).

Between 55 and 60 per cent of the total annual precipitation falls during the months of May, June, July and August. This maximum during the warm season is especially advantageous because significant amounts of moisture may be absorbed by the soil. Most of the precipitation during the cold season is in the form of snow, but probably little moisture is added to the soil during the winter months because it is frozen. The mean annual snowfalls recorded at weather stations in the vicinity of Jamestown are 37.5 and 41.5 inches (U. S. Dept. of Commerce, 1955, p. 33). Most of the snow falls from December through March, but at least a trace of snow has been observed for every month of the year (U. S. Dept. of Commerce, 1955, p. 33). Table 1 summarizes the mean monthly and mean annual precipitation data for two recording stations in the county.

SOILS AND VEGETATION

Chernozem soils are present over most of the county. These soils are dark at the surface and with an increase in depth grade into a grayish-brown to brown color. Concentrations of carbonates are characteristic of the lower part of the soil. Four major associations have been recognized within the chernozem soils in the county (University of Wisconsin Agricultural Experiment Station, 1960, p. 79-81, 114): 1) The "Aastad-Hamerly-Barnes" association in the northeast part of the county, 2) the "Barnes-Aastad" association in the central and southeast part of the county, 3) the "Buse" association, which occurs within the rugged morainal topography of the Coteau du Missouri in the west part of the county, 4) the "Fordville-Lovell" association, which is restricted to areas underlain by glacial outwash along the west border of the county.

Alluvial soils also are present in places along the flood plains of the major streams. These soils are most common in the James River valley.

The natural vegetation of the county consists of grassland that is interrupted by trees and marsh vegetation. The trees are most abundant along stream courses, and the marsh vegetation occurs in poorly drained areas where water is available. Much of the land is utilized for agriculture, principally for pasture land and small grain and hay crops.

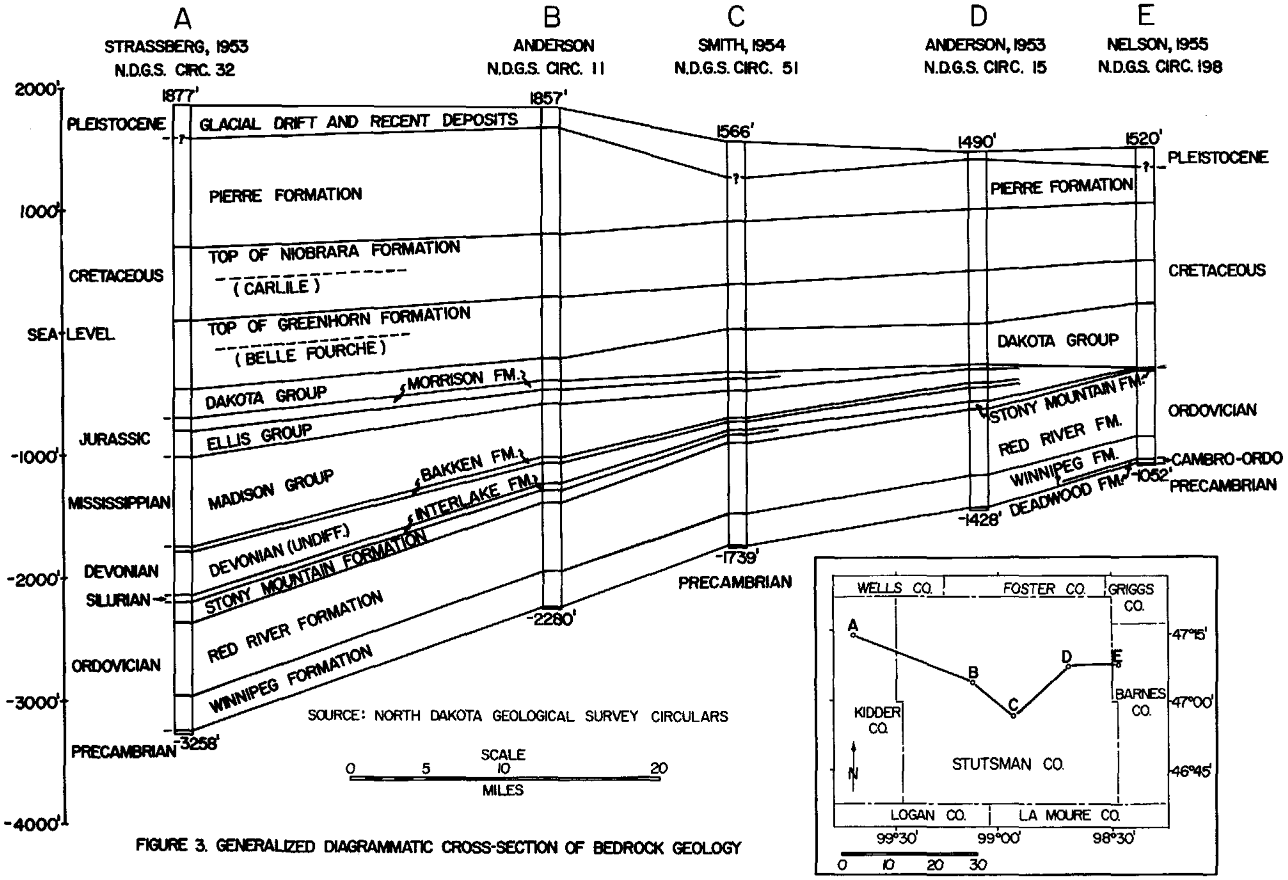
SUMMARY OF THE PRE-PLEISTOCENE STRATIGRAPHY

Although glacial drift covers most of Stutsman County, some information on the pre-Pleistocene geology is available from bedrock outcrops, well logs, and previous reports.[1]

Well logs indicate that 1) the surface of the Precambrian basement rocks decreases in altitude, and 2) the overlying Paleozoic and Mesozoic rocks generally dip and thicken, to the west-northwest toward the Williston Basin (fig. 3).

---

[1] Much of the discussion of the subsurface geology has been compiled from Kline (1942), Towse (1952), Laird (1941), Hansen (1956), and North Dakota Geological Survey Circulars by Anderson (1953), Nelson (1955), Smith (1954a, 1954b), and Strassberg (1953), among others. Sidney Anderson of the North Dakota Geological Survey contributed significantly to the discussion below.



SOURCE: NORTH DAKOTA GEOLOGICAL SURVEY CIRCULARS

FIGURE 3. GENERALIZED DIAGRAMMATIC CROSS-SECTION OF BEDROCK GEOLOGY

PRECAMBRIAN

The surface of the Precambrian basement rocks decreases from approximately 1,400 feet below sea level in the east part of the county to 1,700 feet below sea level in the center of the county. Farther to the west, in northeast Kidder County, the surface of the Precambrian is about 3,200 feet below sea level (wells A, C, D; fig. 3). In all test holes the Precambrian rocks are described as granite.

PALEOZOIC

Paleozoic rocks become thicker and new formations are added downdip to the west-northwest. The sediments are about 1,100 feet and 1,600 feet thick in the east and central parts of the county, respectively, and thicken to approximately 2,250 feet in northeast Kidder County (wells A, C, D; fig. 3). Permian and Pennsylvanian rocks are not known to occur in the county. Well logs indicate that Mesozoic rocks are underlain by the Madison Group of Mississippian age. These rocks consist mainly of limestones and dolomites, which vary from white to pale yellow or gray. The Lower Mississippian Bakken Formation underlies the Madison Group. The Bakken Formation consists chiefly of black carbonaceous shales. Undifferentiated Devonian carbonates, light in color, underlie the Bakken Formation. The Silurian Interlake Formation occurs in the west and central parts of the county but is not recognized in the east. The dominant rocks in the Interlake are pale-orange to pink or white dolomites. Ordovician rocks include, in descending order, the Stony Mountain, Red River, and Winnipeg Formations. The Stony Mountain is a light-colored shaly limestone or dolomite; the Red River consists of limestones and dolomites that vary from yellow or light gray to dark gray or brownish black; and the Winnipeg is made up of gray to green shales and some quartzose sandstones. The Deadwood Formation, of Cambro-Ordovician age, has been recognized in western Barnes County (Nelson, 1955), and it probably extends west into Stutsman County.[2] This formation, which rests on the Precambrian basement rocks, consists of a pale reddish, brown medium-grained glauconitic sandstone and green shale.

MESOZOIC

Mesozoic rocks of Jurassic and Cretaceous age, like the Paleozoic rocks, decrease in thickness from west to east. In eastern Stutsman County these sediments are about 1,500 feet thick, and to the west, in northeast Kidder County, they are more than 2,400 feet thick (wells A, D; fig. 3). The increase in thickness to the west is probably the result of a combination of increased sedimentation toward the west and greater erosion in the east.

Recognized Jurassic sediments include the Ellis Group and the overlying Morrison Formation. The Ellis Group consists of dense limestones, varicolored shales, and fine-grained sandstones; the Morrison Formation is made up of varicolored non-marine shales and shaly sandstones. Recognized Cretaceous rocks include, in ascending order, the Dakota Sandstone, the Greenhorn Limestone, Niobrara Shale, and the Pierre Shale and Fox Hills Sandstone of the Montana Group.[3] The Dakota, important for its water-bearing properties (Willard, 1909), consists of variable sands and shales. The Greenhorn and Niobrara are composed of limey shales. The Pierre Shale is a light to dark-gray shale, and the Fox Hills Sandstone consists mainly of a greenish-gray to yellow sandstone. The Niobrara, Pierre, and Fox Hills Formations are described in greater detail in the following section.

No rocks younger than the Fox Hills Sandstone but older than Pleistocene have been recognized in the area.

---

[2] Oral communication, Sidney Anderson, North Dakota Geological Survey.

[3] Additional formations may exist but, if they do, they are not recognized in North Dakota Geological Survey Circulars 11, 15, 32, 51 and 198, which provided the basis for this discussion.

PREGLACIAL SURFICIAL GEOLOGY

The Niobrara, Pierre, and Fox Hills Formations directly underlie the glacial drift of the county. The formations, originally named by Meek and Hayden in 1862, are Late Cretaceous in age. Only the Pierre is known to crop out in the county; however, the Niobrara and Fox Hills have been recognized directly beneath the glacial drift in exploratory testhole drilling. Much of the information on the characteristics of the formations, their areal extent, and the bedrock topography is based on well logs and water well-inventory data.

NIOBRARA SHALE

The Niobrara Shale is probably the oldest formation that was exposed at the surface immediately before or during the time that the area was glaciated. In test hole 1874 in the NE¼ sec. 11, T. 143N., R. 62W., the Niobrara was found directly underlying glacial drift at an altitude of about 1,033 feet above sea level.[4] Test holes 1872 and 1873, about 1½ miles east and west, respectively, of test hole 1874 show Pierre Shale with surface altitude of 1,204 feet and 1,462 feet above sea level, respectively. Oil exploration well logs from the vicinity record the top of the Niobrara, overlain by the Pierre Shale, at 1,015 feet and 1,070 feet above sea level (wells D, E; fig. 3). This, as well as other subsurface data, indicates that where the Niobrara directly underlies glacial drift, a bedrock valley exists (pl. 2). The valley may have been cut into the Niobrara in preglacial or in glacial times, but the former interpretation is more likely, in the writer's judgment, because an extensive preglacial drainage system exists on the bedrock surface. (See Bedrock Topography.) Only one test hole reveals the Niobrara directly beneath glacial drift in the county. Similiar relationships undoubtedly exist wherever stream erosion has cut valleys through the Pierre Shale in preglacial or glacial times. If the above interpretation is correct, the areal extent of the Niobrara covered by glacial drift is restricted to the lower portions of such valleys.

The Niobrara Shale consists of medium gray calcareous shale that may contain white specks and pyrite inclusions. The shale fractures along smooth planes.

Approximately 60 feet of the Niobrara Shale is recorded in test-hole log 1874 in the east part of the county. The top of the formation is recorded at 1,033 feet above sea level, and the hole was abandoned at 971 feet above sea level before any other formation was penetrated.

PIERRE SHALE

The Pierre Shale underlies glacial drift in most of the county and is believed to overlie the Niobrara Shale everywhere except where it has been eroded away. One hundred sixty-four out of 167 exploratory test holes that penetrated bedrock in the county reveal the Pierre directly underlying glacial drift.

The Pierre Shale crops out in three areas in the county but is not exposed continually for distances more than several thousand feet (pl. 1). Outcrop areas are 1) along the walls of the James River valley and several of its tributary valleys extending from Jamestown north for about 17 miles to Jim Lake; 2) in a limited area along the walls of Pipestem Creek valley 3 to 4 miles northwest of Jamestown; and 3) along the lower part of Beaver Creek valley east of Sidney. In addition to the above, an outcrop of the Pierre may occur along the west wall of the Pipestem Valley in the NE¼ sec. 1, T. 142 N., R. 66 W. At this location shale, overlain by 1 to 3 feet of till, has a minimum thickness of 10 feet. Although the shale is highly weathered, it seems to be in place.

When unweathered, the Pierre is a dark-gray to black non-calcareous shale that lacks distinct bedding planes. The shale is highly jointed, and red iron stains

---

[4] Identification of the sample was confirmed by Sidney Anderson, North Dakota Geological Survey, 1961 (cross-section A-A').

are common along the fractures. Iron concretions are abundant, but no fossils were observed in the shale. Unweathered exposures are limited to recent excavations and to outcrops along the shore of the Jamestown Reservoir, where wave action has removed weathered shale, glacial drift, and colluvium.

Where weathered, as is generally the case in outcrops, the shale breaks down into small flakes which average 1 to 2 millimeters in thickness and 1 to 2 centimeters in length (fig. 4). These small flakes are light blue gray when dry and dark gray when wet. In weathered outcrops the concretions, which average 2 to 4 inches in diameter, are especially apparent because they weather out at a slower rate and remain as residuals. In most outcrops where drift overlies bedrock, the shale is weathered, and the contact between the two is represented by a transitional zone which averages several feet in thickness.

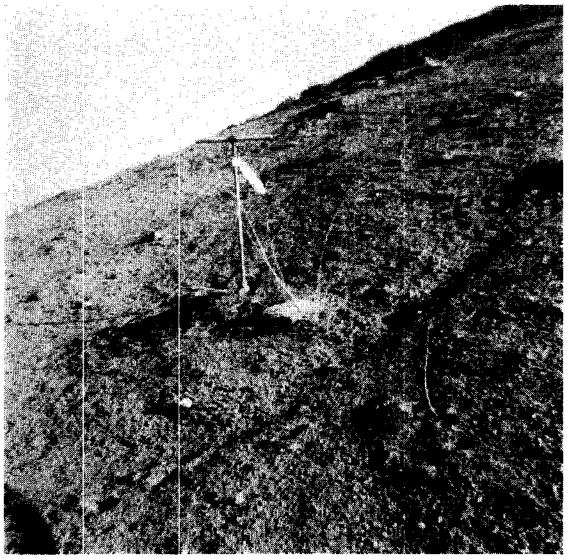


FIGURE 4

Outcrop of highly weathered Pierce Shale along county road in the NE¼ sec. 2, T. 141 N., R. 64 W. Most outcrops of bedrock in the county show a similar degree of weathering.

Kresl (1956) recognizes five bentonite beds. They range from a fraction of an inch to 5 inches in thickness and are found within the shale along the west wall of the James River valley in the SW¼ sec. 35, T. 142 N., R. 64 W. In addition, one bentonite bed, about 2 inches thick, is present along the west wall of the James River valley in the SE¼ sec. 23, T. 140 N., R. 64 W., just north of Jamestown. The bentonite is yellow to light tan; its color is in sharp contrast to that of the shale.

Minor concentrations of subsurface water are present in the bentonite layers. In the first of the two locations described above, vegetation is in greater abundance where the bentonite crops out. The vegetation pattern reflects the local variation in water concentration.

In Stutsman County the thickness of the Pierre Shale ranges up to more than 900 feet. Oil exploration well logs reveal an increase in thickness from about 350 feet in the east to about 950 feet in the west-central part of the county (wells B, D; fig. 3). Regionally the shale becomes thicker to the west-northwest. However, the surface of the Pierre has considerable relief, and great variations may be found in short distances (pl. 2; see Bedrock Topography).

Three major joint patterns in the shale are easily seen in the shallow waters on the east side of the reservoir 200 feet north of the Jamestown Dam. The dominant joint system strikes N 40°E and dips 66°S. The second and third joint systems, of similiar magnitude, strike N 90°E and N 40°W and dip 71° N and 72° S, respectively. In addition, numerous minor joints are present.

In the SW¼ sec. 25, T. 143 N., R. 64 W., the bedding in the upper part of a 22-foot exposure of weathered shale exhibits severe contortions. Shale in the lower part of the same outcrop is not deformed. The contortions most likely resulted from forces exerted by the glacier as ice moved over the area.

The Pierre dips to the west-northwest at about 5 to 10 feet per mile in conformance with regional structure.

FOX HILLS SANDSTONE

The Fox Hills Sandstone overlies the Pierre Shale and is the youngest pre-Pleistocene formation which is recognized in the county. Its known extent is limited to the southwest part of Stutsman County, where test holes 1906 and 1907 reveal surface altitudes of 1,811 feet and 1,870 feet above sea level respectively. In both instances the formation is overlain by glacial drift. The altitude of the bedrock surface is lower to the north, east, and south (pl. 2). The Fox Hills probably is associated with a bedrock high in this area. Although no outcrops of Fox Hills are known in the county, they have been reported west of the area (Kline, 1942, p. 355; Bonneville, 1961, p. 15-23; Rau *et. al.*, 1962, p. 7, 18-19).

The Fox Hills Sandstone is made up of greenish-gray to yellow fine- and medium-grained sandstone that may be interbedded with dark-green to gray siltstone and shale.

Information regarding the thickness of the Fox Hills is limited to the two test holes mentioned above. Test hole 1907 penetrated from 26 to 32 feet of the formation. Test hole 1906 was drilled through the Fox Hills and into the underlying Pierre Shale. About 300 feet of the Fox Hills is recorded in the well log.

FOX HILLS PROBLEM. — The log of test hole 1906 records the contact between the Pierre and Fox Hills Formations at about 1,650 feet above sea level.[5] The base of the Fox Hills sandstone is significantly lower than the altitude of the Pierre Shale to the east and south; no information is available on the west. Test holes 1579 to the west, and 313 to the south record the top of the Pierre at about 1,738 feet, and 1,810 feet above sea level, respectively. The solution of this anomaly, the low altitude of the Fox Hills relative to the Pierre, is not possible with the available information, but one or more of the following hypotheses may be appropriate: 1) The Fox Hills may channel into the Pierre Formation even though no evidence of it has been recognized in the subsurface in the immediate vicinity to the south or east; 2) the situation may result from an increase in the local dip from an average of 5 to 10 feet per mile to an excess of 40 feet per mile; 3) locally the Fox Hills may have been down-faulted; 4) the situation may reflect a facies change in the Pierre Shale.

BEDROCK TOPOGRAPHY

The bedrock topography, shown on plate 2, was interpreted on the basis of about 200 test holes drilled in Stutsman County and a small number of additional test holes in adjacent counties.[6] In addition, data from more than 800 water wells were utilized to determine, within limits, bedrock elevations.[7] The contour lines on plate 2 are generalized, the slope characteristics of the bedrock surface are not known, and only the larger bedrock valleys are shown on the map. The bedrock

---

[5] The altitude of the contact is based mainly on interpretation of the test-hole log because the electric log is inconclusive.

[6] About 165 test holes were drilled into bedrock; the remaining were abandoned at various depths in glacial drift because of drilling problems.

[7] This information was obtained from an inventory of the wells in the county. Only wells in which the surface altitude, depth of well, and aquifer were known or reported were considered. See plate 2.

surface of the county consists of an extensive plain which is interrupted by separated bedrock highs along the west and northwest borders of the county and which is dissected by deep valleys cut into its surface. Test-hole data indicate that the maximum relief on the bedrock surface in the county exceeds 900 feet (test holes 1594 and 1907).

BEDROCK HIGHS

Three distinct bedrock highs are present in the southwest, west-central, and northwest parts of Stutsman County (pl. 2). All three rise more than 300 feet above the general altitude of the extensive bedrock plain. The most extensive bedrock high is in the southwest part of the county. Test-hole data indicate that the bedrock surface reaches a minimum altitude of 1,870 feet some 5 miles north-northwest of Streeter (test hole 1907). This bedrock high probably extends several miles west into Kidder County, where, according to Carlson (Rau, *et. al.*, 1962, fig 16), the bedrock altitude exceeds 1,900 feet above sea level. In Stutsman County the bedrock high is supported by both the Pierre and the overlying Fox Hills.

A second bedrock high, in the west-central part of the county and probably the smallest of the three, reaches a minimum altitude of 1,850 feet above sea level (test hole 1893). Only test hole 1893 is drilled into bedrock high, but nearby test holes provide some limits to the maximum possible dimensions of the feature.[8] The bedrock high is supported, at least in part, by the Pierre Shale (test hole 1893). The Fox Hills is not known to be present, but, because of the small amount of subsurface data, the possibility should not be entirely discounted.

The third bedrock high is along the north border in the northwest part of the county. The altitude of the bedrock exceeds 1,900 feet, but the shape of the feature is, in part, speculative because of lack of subsurface control to the north and west. A test hole (located) 1 mile north of the county line in sec 2, T. 145 N., R. 68 W., penetrated the Pierre Shale at an altitude of 1,921 feet above sea level. The Fox Hills Sandstone is not known to be present in this feature, but it does crop out more than 1,900 feet above sea level about 18 miles to the west in Kidder County (Chmelik, 1960, pl. I). Carlson (Rau *et. al.*, 1962, fig. 16) shows a bedrock high which is associated with this outcrop and which extends from Kidder County to the west border of Stutsman County. The bedrock high, supported by the Fox Hills Sandstone in Kidder County, may extend east to join the bedrock high supported by the Pierre Shale in Stutsman County. Lack of subsurface control in northeast Kidder and northwest Stutsman Counties, however, makes this interpretation speculative.

INTERMEDIATE BEDROCK SURFACE

An extensive dissected plain is the most widespread landform that is associated with the bedrock topography. Bedrock highs, discussed previously, rise above the plain in the west and stream-eroded valleys dissect the surface. The plain has an altitude of about 1,400 feet to 1,500 feet above sea level and is well represented on plate 2 in the central part of Stutsman County. Throughout the county the plain is known to have been developed only on the Pierre Shale.

BEDROCK VALLEYS

Subsurface data indicate that a considerable amount of relief exists on the bedrock surface in Stutsman County. In the writer's judgment this relief has resulted largely from stream dissection that cut a system, or systems, of valleys into the bedrock surface. The following factors, however, limit the precise description and the validity of interpretations of the bedrock valley: 1) The limited amount of subsurface data prohibits the recognition of smaller valleys, and, in some instances, presents difficulty in definitely determining the location or margins of

---

[8] Test holes 1552, 1814, 1815, 1819, 1895, and 1901 were drilled on all sides of the bedrock high and indicate that the surrounding bedrock surface ranges from 1,411 feet to 1,534 feet above sea level.

the major valleys; 2) the altitude of the valley bottoms are subject to question because it is not known that the test-hole data or water-well information records the deepest part of the valleys; 3) from the available information the writer cannot, in most instances, determine with certainty the direction in which the valley decreases in altitude; 4) an orderly system of valley development (e.g., dendritic) may have been interrupted one or more times by drainage diversions resulting from past glaciation; and 5) the present-day glacial topography does not reflect the subsurface valley system.

Undoubtedly much of the dissection of the bedrock surface took place in preglacial times. This is indicated by the marked unconformity between the Cretaceous bedrock formations and the Pleistocene sediments. Dissection of the bedrock surface continued to some extent during Pleistocene time as shown by the James River, which has eroded a channel into bedrock north of Jamestown. With few exceptions (Leonard, 1916a, 1919a) geologists believe that the drainage systems of the northern Great Plains, including all of North Dakota, were oriented to Hudson Bay prior to glaciation (Todd, 1896, p. 57, 1914, 1923; Alden, 1924; Flint, 1949b, 1955, p. 139-143 and pl. 7; Benson, 1952, p. 160-181 and fig. 12; Warren, 1952; Lemke and Colton, 1958, p. 42-43 and fig. 2; Howard, 1960, p. 77 and pl. 8; among others). The major preglacial stream that trended northeast through south-central North Dakota may be the ancestral Cannonball River (Benson, 1952, fig. 12; Lemke and Colton, 1958, fig. 2). A preglacial valley, interpreted as the ancestral Cannonball, has been traced east through Kidder County (Benson, 1952, 166-167, fig. 12; Lemke and Colton, 1958, fig. 2; Rau *et. al.*, 1962, fig. 16) and enters Stutsman County about 8 miles southwest of Woodworth (pl. 2). The valley extends northeast for 12 miles from the western border of the county but its course from that point on is subject to question. Three possible continuations of the valley are discussed below.

1. The Southeast Extension: Subsurface evidence indicates that a bedrock low extends southeast through the county from the eastern-most known position of the bedrock valley which is interpreted as that of the ancestral Cannonball River. The bedrock low is associated with a valley in the south half of the county, but its form is not clear in the north half. The bedrock low may represent the course of the preglacial Cannonball River (pl. 2, arrow A); the bedrock low may have been formed by a tributary to the preglacial Cannonball River; the bedrock low may have been developed by two or more opposing tributaries dissecting an interfluve between two separate drainage systems; or the bedrock low was developed by a glacial diversion channel resulting from earlier glaciation. The first explanation may be questioned on the basis that such a course would involve an abrupt change in the trend of the valley from northeast to southeast without any apparent reason. The second alternative is doubtful if the ancestral Cannonball continued east through the county (pl. 2, arrow B) because an unusual barbed drainage pattern would result. This explanation would be more acceptable if the ancestral Cannonball drained north through the county (pl. 2, arrow C). The third alternative is, in part, similiar to the second and is neither supported nor rejected by subsurface evidence. The fourth alternative also lacks supporting evidence but is worthy of consideration because diversions of preglacial streams by glaciation would be expected in the area. (For additional discussion regarding diversions, see Flint, 1955, p. 143.)
2. The East Extension: The preglacial valley of the Cannonball River possibly extends east across northern Stutsman County (pl. 2, arrow B) to enter Foster County in the vicinity of Arrowood Lake. Several test holes reveal relatively low bedrock altitudes (test holes 1877a, 1879, 1882), but control is not sufficient to define a valley in this area.
3. The North Extension: The third possible continuation of the ancestral Cannonball Valley extends north (pl. 2, arrow C) to leave the county in the extreme northwest corner. Little is known regarding the bedrock surface in this part of the county. This alternative is only a possibility, and it is not based upon any subsurface indications.

In conclusion, the exact course of the ancestral Cannonball River valley in the county is in question, but, if it has been identified and traced correctly through Kidder County to the west, it must have followed one of the three courses described above.

The deepest known bedrock valley, hereafter referred to as the Spiritwood Valley (Huxel, 1961, p. 179-181), trends north-south along the border between Barnes and Stutsman Counties.[9] The floor of this valley has an altitude of less than 1,000 feet above sea level in the east-central part of the county (test hole 1594) and is 400 to 500 feet lower than the intermediate bedrock surface previously described. The width of the valley is more than 2 miles in places and may considerably exceed this figure. This valley has been cut through the Pierre Shale and into the top of the Niobrara Shale in at least one locality. (See Preglacial surficial geology.) Subsurface evidence does not indicate whether the valley decreases in elevation to the north or to the south. Based on the magnitude and trend of the valley it may be a northward continuation of the pre-diversionary Cheyenne River system recognized by Flint (1955, p. 148, pl. 7) in South Dakota; it may represent a continuation of the ancestral Cannonball River valley; or it may be associated with a bedrock valley system that is not recognized in North Dakota at this time.

No additional major bedrock valleys have been found in the county. Numerous tributary valleys are present, however, and some reach considerable size. Plate 2 indicates some of these tributary valleys. In all probability the bedrock surface is dissected to a greater degree than that shown on plate 2, and smaller bedrock valleys, though not shown on the map, are abundant.

GLACIATION OF NORTH DAKOTA — A GENERAL STATEMENT

North Dakota except the southwest corner was glaciated during Pleistocene time. It is not definitely known that glaciers representing all the stages of Pleistocene glaciation reached the State. Although evidence is lacking, pre-Wisconsin glaciation must have occurred in the State if correct interpretations regarding the older drift in South Dakota have been made (see Glacial Map of the U. S. East of the Rockies, Geol. Soc. Amer., 1959). Much of the State was glaciated, especially that part of it lying north and east of the Missouri River, during Wisconsin time. Drift of Wisconsin age as old as Iowan (?) and as young as Mankato has been tentatively recognized (among others, Lemke and Colton, 1958, figs. 3, 4, and 5). Stutsman County lies in the area glaciated during Wisconsin time. The relative positions of various glacial landforms indicate that the direction from which the ice advanced ranged from north-northwest to east, the dominant direction being from the northeast.

Glaciation resulted in marked changes in the topography and drainage of Stutsman County. The glaciers eroded the bedrock surface and deposited glacial drift, which ranges generally from 10 to 500 feet in thickness. In general, the greatest amount of glacial deposition occurred in the west half of the county in the area known as the Coteau du Missouri and in bedrock valleys in the east half of the county. As a result, the only reflection of the preglacial bedrock surface in the present-day topography is a regional increase in altitude from east to west. The increasing altitudes to the west, however, only indirectly reflect the rise in bedrock altitudes because the bedrock surface is very irregular and is almost everywhere overlain by a large amount of glacial drift. Individual features associated with the bedrock surface, such as bedrock highs and valleys, are not apparent in the present topography; thus, glaciation has subdued the relief in the county. This is especially true in the relatively flat east part of the county. In the west half

[9] This valley is named after the town of Spiritwood, which is in the east part of Stutsman County in the vicinity of the bedrock valley.

the local relief associated with glacial landforms is relatively large, although it is less than that which existed on the preglacial bedrock surface.

The major streams of the county established their courses during Pleistocene time and were not noticeably affected by preglacial bedrock topography. In some places the present-day stream valleys have been developed across preglacial bedrock highs. In some instances the streams that cut the valleys have eroded down through the blanket of glacial drift and have exposed bedrock (e.g., the James River north of Jamestown). Probably the preglacial drainage system was oriented north to Hudson Bay, but Pleistocene glaciation has resulted in a reversal of drainage direction.

PLEISTOCENE SEDIMENTS AND THEIR ASSOCIATED LANDFORMS

Three types of glacial sediments are common in the county:)1 Till, 2) glaciofluvial material, and 3) glaciolacustrine sediments. In addition varying amounts of postglacial sediments are present; these include: 1) Recent alluvium, 2) colluvium, and 3) recent wind-blown materials. Many times a direct relationship exists between the nature of the sediments and the topographic forms in the landscape. The following discussion includes a general description of the sediments and of the landforms found in association with them.

TILL

Till may be defined as unstratified and assorted materials, heterogeneous in nature, deposited by ice without significant modification by water or wind (in part from Thwaites, 1959, p. 30). Till may be deposited beneath and at the margin of a glacier and, in some instances, may accumulate upon the surface of a glacier and be deposited upon the subglacial topography by ablation of the underlying ice. The surficial till in Stutsman County is generally brownish yellow and consists mainly of clay, silt, and sand. Though pebbles, cobbles, and boulders occur, the large amount of fine material makes the till dense and tight. The till is sticky when wet and does not readily absorb surface water. Till is the most abundant glacial sediment in the county and underlies much of the landscape.

Landforms Associated with Till. — Major landforms that consist largely of till include ground moraine and associated minor recessional features, end moraine, and hummocky stagnation moraine.

There appears to be some lack of agreement regarding the specific form and origin of ground moraine.[10] For the purposes of this study ground moraine is defined as a gently undulating surface, underlain for the most part by till and exposed during deglaciation by an ice margin that retreated in an orderly manner.[11] Ground moraine that has an average relief of 10 to 20 feet per square mile, resulting in gently undulating topography, is widespread in the east part of the county. (pl. 1).

Parallel linear ridges that average 200 feet in width and seldom exceed 2 miles in length or 10 feet in height are found in some areas of ground moraine. The ridges are composed mainly of till that exhibits laminated structure in some places. These landforms are difficult to identify in the field but may easily be seen on aerial photographs. They are found only in groups with a distinct linear pattern.

The landforms and the pattern they display are similiar, if not identical, to "swell and swale" topography described by Gwynne (1942, p. 202), washboard

---

[10] For example, see Flint (1955, p. 111-112 and 1957, p. 131) and Thwaites (1959, p. 45).

[11] The term "orderly manner" means a continuing tendency toward orderly retreat, eliminating the possibilities of a significant still-stand of the ice margin or extensive stagnation of the glacier. Retreat in an orderly manner, however, may include variations in the rate of retreat or minor advances of the ice margin resulting from changes in subglacial topography, or seasonal variations in climate.

moraines (Elson, 1957b; Lemke, 1960, p. 45-46; Christiansen, 1960, p. 15-16; 1961, p. 17; Winters, 1960, p. 75-80), washboard ridges (Gravenor and Kupsch, 1959, p. 54-55), minor end moraines or minor recessional ridges (Christiansen, 1956, p. 13-15), and "bars" (Howard, 1960, p. 86-88). The term "washboard moraine" is used for the forms in this report.[12] Elson (1957b, p. 1721) believes that the ridges were formed by deposition of lodgment till where plastic ice was thrust over or against dead ice at the periphery of a glacier. The writer agrees with Elson's interpretation and defines washboard moraines as minor recessional features, present only in groups, composed mainly of till, and possessing a distinct linear arrangement resulting from deposition parallel to the margin of a glacier. If this interpretation is correct, the areal pattern of washboard moraines records, at least in part, the former configuration of the ice margin and may give some indication of the direction and manner in which the ice margin receded (fig. 5).

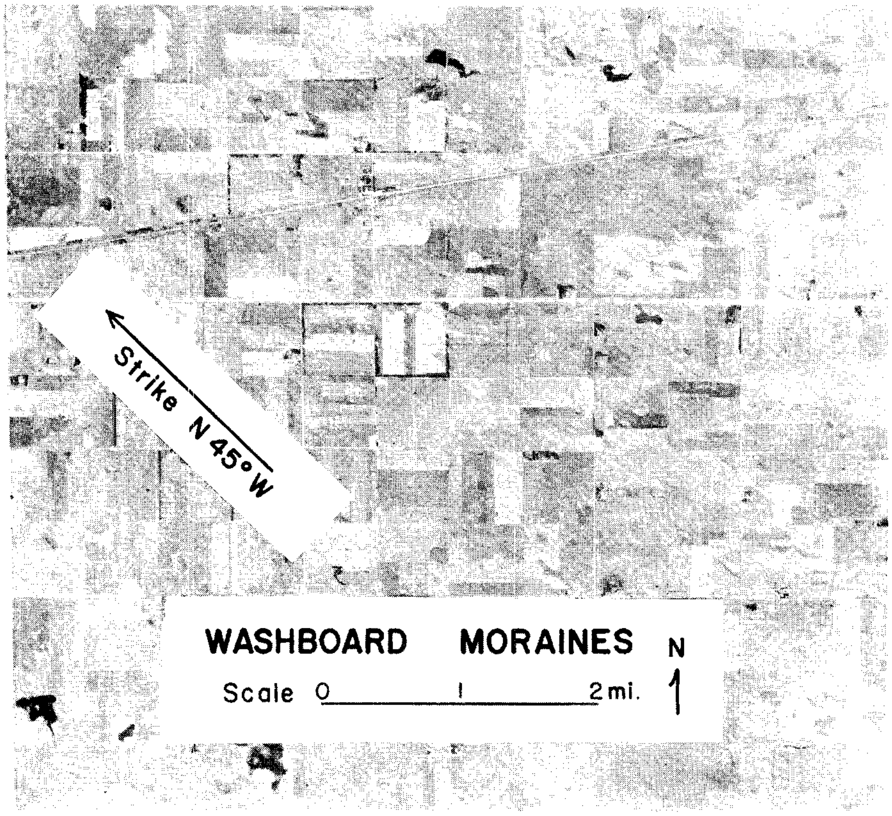


FIGURE 5—Aerial photograph showing numerous washboard moarines in the vicinity of Eldridge, which is shown in the north-central part of the photo. Photograph by the Corps of Engineers.

An end moraine consists of a ridge-like accumulation of glacial drift that displays an overall or internal linear pattern, which indicates construction at the

---

[12] The washboard moraines in Stutsman County may have a different origin from those described by Mawdsley (1936, p. 9).

margin of an active glacier. End moraines probably developed when the rate of ablation approximately equaled the rate of ice movement. As a result, the ice margin may have remained in the same position for a significant period of time. Thus, end moraines mark a former position of an ice margin. The end moraine may have been formed during a halt in the retreat of an ice margin or may mark the position of an ice margin during a readvance.[13]

Several end moraines are present in the county (pl. 1). They are comprised mainly of till and the local relief may range from 20 to 100 feet per square mile, which results in a hilly or rugged landscape in comparison with areas of ground moraine (fig. 6).

Hummocky stagnation moraine, along with various other landforms, may form when a glacier is stagnating throughout a relatively extensive area. As a

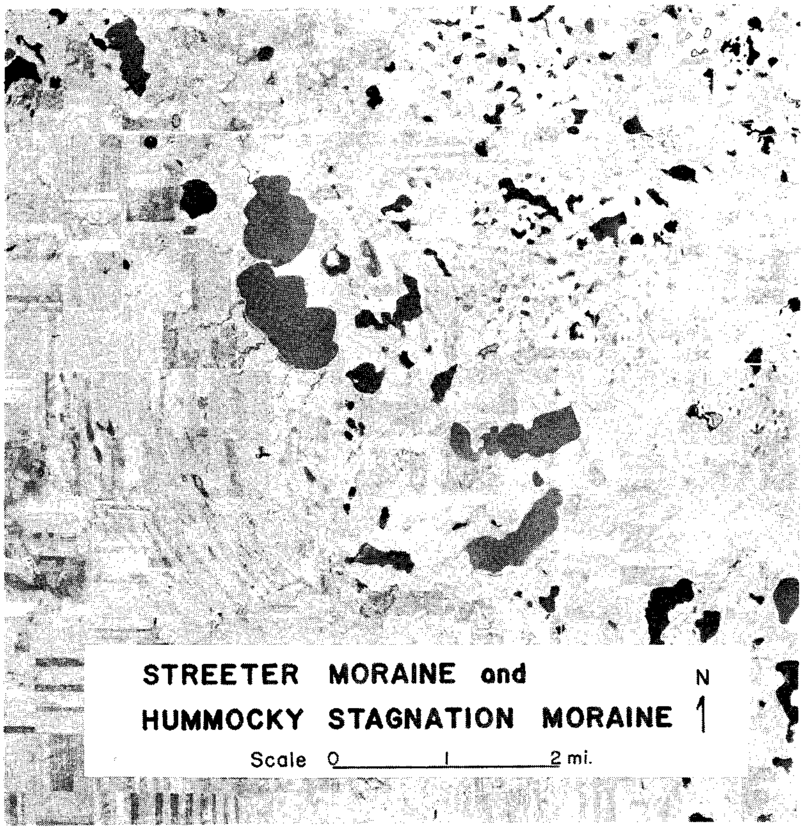


FIGURE 6—Aerial photograph showing the Streeter moraine and hummocky stagnation moraine. The Streeter moraine is characterized by linear patterns in this area and presents a sharp contrast to the hummocky stagnation moraine to the northeast. Streeter is located in the right part of the photo. Photograph by the Corps of Engineers.

---

[13] Flint (1955, p. 111-117) presents a discussion of end moraines that proved especially useful to the writer in both field work and the preparation of this report.

result of stagnation, the glacier disintegrates in place and an ice margin that is either advancing or retreating in an orderly fashion is absent.[14] When a glacier disintegrates in this manner, a rugged glacial topography consisting of closely spaced hills and closed depressions and which lacks an internal or overall linear pattern may result. Gravenor and Kupsch (1959, p 50) have described a similar landscape as "a nondescript jumble of knolls and mounds of glacial debris separated by irregular depressions." Landforms of this nature, composed mainly of till, are widespread in the west part of Stutsman County in the Coteau du Missouri. In contrast to the ground moraine so widespread in the east half of the county,

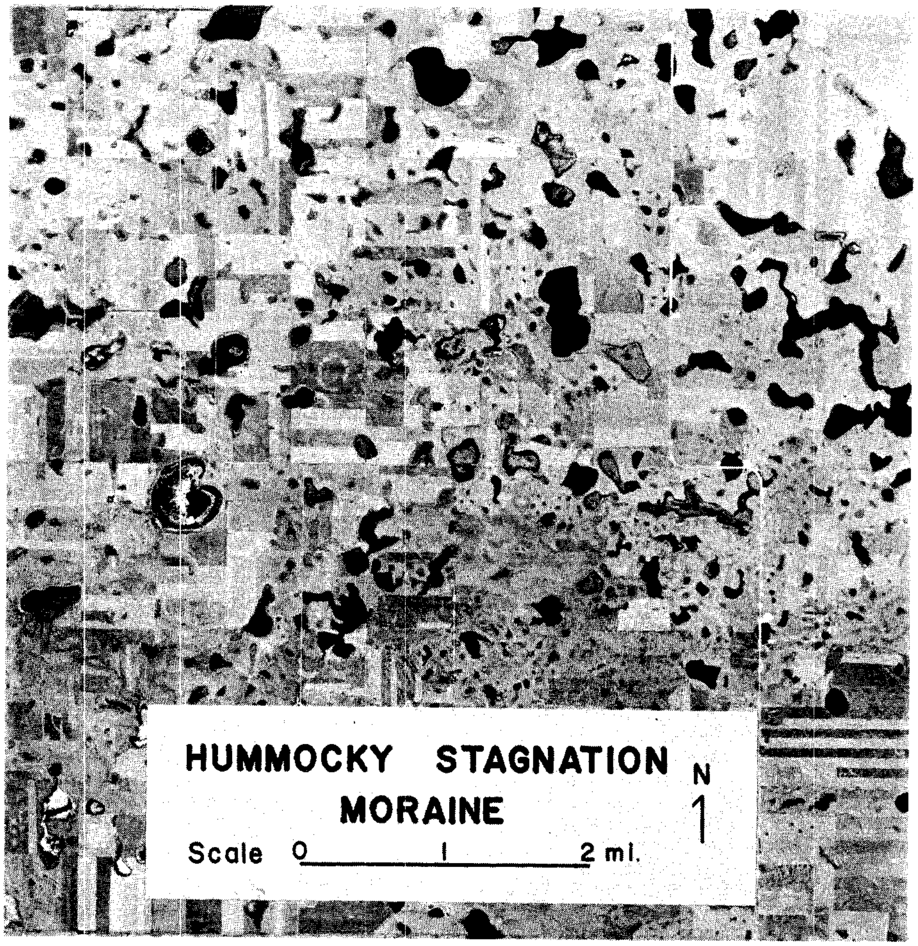


FIGURE 7—Aerial photograph of hummocky stagnation moraine in the west part of the county. Photograph by the Corps of Engineers.

---

[14] For works dealing with the concept of stagnation see Flint (1929; 1930; 1932; 1955; p. 114; 1957, p. 163-164), Hoppe (1952), Gravenor (1955), Gravenor and Ellwood (1957, p. 12-17), Gravenor and Kupsch (1959), Christiansen (1956, p. 9-12; 1959, p. 12-16), Bayrock (1958a, p. 11-12; 1958b, p. 6-7), Lemke and Colton (1958, fig. 5), Lemke (1960, p. 113-114), Leighton (1959b), Thwaites (1959, p. 15, 17-18, 47-48), Stalker (1960a; 1960b, p. 27-35), Winters (1961), among others.

local relief in the Coteau area may exceed 100 feet per square mile. Hummocky stagnation moraine lacks the orderly linear pattern generally associated with end moraines (figs. 6 and 7).

GLACIOFLUVIAL MATERIALS

Glaciofluvial sediments are deposited by streams flowing from glaciers. The materials consist mainly of stratified sand and gravel which may be deposited either in direct contact with the glacial ice or outward from the margin of the ice sheet. The former may be referred to as ice-contact deposits and the latter may be described as proglacial sediments.

ICE-CONTACT GLACIOFLUVIAL SEDIMENTS. — Ice-contact sediments are characterized by large variations in grain size, structure, and petrologic characteristics.

Sediments may range in size from large boulders to fine sand inter-bedded with till, clay and silt. The contacts between sediments of different sizes may be very sharp or transitional. Slump structures may be abundant, indicating loss of support resulting from the melting of glacial ice. Shale, which is generally in the form of small pebbles, granules, and sand, is common in most ice-contact deposits in the county. Most of the pebbles are carbonates, but most of the cobbles and boulders are crystalline.

LANDFORMS ASSOCIATED WITH ICE-CONTACT GLACIOFLUVIAL SEDIMENTS. — Eskers; kames, alone or in groups; kame terraces; and complex forms associated with extensive stagnation of glacial ice are present in the county. An esker may be defined as a winding, irregularly crested ridge that consists of glaciofluvial sediments. The sediments are generally interpreted as having been deposited in the beds of streams that flowed upon, within, or beneath a glacier (Flint, 1957, p. 158-159). Ablation of the adjacent ice leaves the sediments in the form of a ridge that marks the former course of the glacial stream. The largest esker in the county, located 4 miles south of Jamestown, rises 15 to 20 feet above the surrounding ground moraine and consists of six elongated segments that range from approximately 500 to 2,000 feet in length. Other eskers are present in the county but none exceed 2 miles in length (pl. 1).

A kame may be defined as ". . . a moundlike hill of ice-contact stratified drift" (Flint, 1957, p. 150). Kames may originate from deposition in openings within a glacier (moulin kame) or may form as aluvial fan-like features at the margin of the ice sheet (frontal kame). Kames are abundant in Stutsman County and range in size from small isolated features, 10 to 20 feet high and several tens of feet in diameter, to large groups of coalescing kames (referred to as kame complexes) possibly exceeding 50 feet in height and covering several square miles (pl. 1). Small kames are especially abundant several miles south and southeast of Jamestown. The largest kame complex is found in the west-central part of the county approximately 9 miles north-northwest of Medina.

Kame terraces consist of ice-contact glaciofluvial material deposited between glacial ice that partly occupies a valley and the valley wall. After the ice melts, the deposit remains in the form of a constructional terrace along the valley wall. The only kame terraces in Stutsman County are in the part of Sevenmile Coulee south of Spiritwood Lake and north of the point where the coulee is crossed by the Northern Pacific Railroad. The terraces are 10 to 20 feet higher than the bottom of the valley and are present along both sides.

Melt water from an ice sheet characterized by extensive stagnation may deposit sand and gravel on the surface of the glacier and in various openings within and beneath the ice. The landforms associated with the ice-contact glaciofluvial sediments may be intermixed with hummocky stagnation moraine. The landforms may range in size and extent from small kames and eskers to large irregular tracts underlain by outwash that was deposited, at least in part, by melt water from the disintegrating ice. Landforms associated with extensive glaciofluvial deposits that formed in this manner are referred to in this report as stagnation outwash forms. The configuration of landforms associated with stagnation outwash may be very complex and in some instances cannot be recognized easily on the basis of their topography alone.

Proglacial Fluvial Sediments. — Sand and gravel deposited outward from the margin of an ice sheet by running water are proglacial rather than ice-contact sediments. At many places the sediments have nearly horizontal bedding and the size of the material tends to decrease as the distance from the former ice margin increases. Sediments deposited close to the ice margin may contain numerous boulders and cobbles, while farther away pebbles or granules may represent the coarse fraction. Cross-bedding is common and gives some indication of the direction of movement of the glacial melt water. In Stutsman County petrologic identification of pebbles indicates that the sedimentary stones, mainly limestone, dolomite, and shale fragments, tend to be most abundant. Igneous pebbles are more abundant than metamorphic types, and the two combined may constitute more than 40 per cent of the pebbles in some gravel, although the average appears to be less. Sediments smaller than medium sand (less than ¼mm.) are generally present only in very small amounts. In most cases, proglacial fluvial sediments range in size from medium sand to pebble gravel.

Landforms Associated With Proglacial Fluvial Sediments. — Most of the proglacial sand and gravel deposits are in the form of valley trains or outwash plains. A valley train consists of glaciofluvial materials deposited in a preexisting valley. As a result of this deposition, a wide valley may have a broad, flat bottom underlain by a considerable thickness of sand and gravel. Examples of valley trains are present in the James River valley south of Jamestown and in parts of the Pipestem Creek valley.

Outwash plains may be divided into two major types: 1) Non-pitted outwash plains, and 2) pitted outwash plains. Both are underlain by glaciofluvial material deposited outward from an ice sheet by melt-water streams forming ice-marginal plains. The two differ markedly, however, on the basis of topography; the non-pitted outwash plain is a surface of low local relief that may be characterized by a gentle slope away from the former position of the ice margin. A pitted outwash plain may possess a similiar slope, but the local relief is rugged because of numerous pits, or closed depressions, within the plain. The pits were formed as a result of the melting of isolated blocks of ice that had been buried by glaciofluvial sediments; the melting permitted the sand and gravel to collapse to form the pits. Both pitted and non-pitted outwash plains exist in the county. The former cover an extensive area 8 to 10 miles southwest of Woodworth; an example of the latter is found north of Buchanan.

LACUSTRINE SEDIMENTS

Lacustrine sediments are those deposited from water in a lake. Although lacustrine deposits contain a few larger-sized particles, most of the lake sediments in Stutsman County consist of clay, silt and fine sand; they have laminated structure. Proglacial lacustrine sediments are known extensively in at least twenty areas in the west part of the county. Postglacial lacustrine materials exist in varying amounts in closed depressions throughout the county.[15]

Landforms Associated With Lacustrine Sediments. — As the glacier stagnated in the west part of the county, lakes formed that were walled, at least in part, by the ice. These lakes received sediments that were deposited on the lake bottom in more or less horizontal layers. As the adjacent ice disintegrated, the former lake bottoms emerged as relatively flat lacustrine plains that are in sharp contrast to the nearby hummocky stagnation moraine and the stagnation outwash forms. Frequently the lacustrine plains are found at higher altitudes than the stagnation forms mentioned above. Landforms that originate in this manner might best be

---

[15] Postglacial lacustrine sediments were mapped only where they cover a large area. Many deposits in the numerous closed depressions are not shown on plate 1.

described as ice-restricted, elevated lacustrine forms, but for convenience they will hereafter be referred to in this report as perched lacustrine deposits.

Within the county postglacial lacustrine sediments occupy low areas or plains that vary greatly in size. These areas generally have flat surfaces and are underlain by lacustrine sediments. They are surrounded by higher land and some — locally called "potholes" or "prairie potholes" — contain water much of the time. Post glacial lacustrine plains may still be in the process of formation. This is best shown in the numerous lakes and sloughs in the county that are undoubtedly receiving some sediments from the adjacent higher areas.

OTHER POSTGLACIAL SEDIMENTS

Other postglacial sediments include: 1) Recent alluvium in the flood plains of streams, 2) colluvium associated with steep slopes, and 3) small amounts of wind-blown materials, mainly clay and silt.[16]

ANALYSIS OF THE SURFICIAL TILL IN STUTSMAN COUNTY

The characteristics of the till were observed closely in an attempt to recognize different drift sheets within the county. If more than one till could be identified and differentiated on the basis of physical characteristics, rock stratigraphic units could be recognized. As the study progressed, it became apparent that the surficial till was similiar throughout the county and that differentiation was difficult, if not impossible. Following is a discussion of the characteristics of the surficial till which is based on field observations, test-hole logs, and laboratory analyses of till samples collected at various locations in the county.

LEACHING AND CALICHE

At many localities in the county the surficial till was tested for leaching of carbonates with a dilute solution of hydrochloric acid. In practically all places the amount of leaching was negligible and did not provide a basis for differentiation of separate surficial tills.

A concentration of calcium carbonate, or caliche, is common directly beneath the dark upper soil zone. Pebbles within the caliche zone are often encrusted with calcium carbonate. Though the amount of caliche varies greatly in the surficial till, this characteristic does not provide a basis for differentiation of tills because large variations may exist in a single exposure of drift that is the same age. Thus the depth of leaching and the amount of caliche accumulation do not provide reliable bases for differentiation of separate surficial tills in Stutsman County. Previously Howard (1946, p. 1204; 1960, p. 30) arrived at the same conclusion for another area in northwest North Dakota and northeast Montana.

OXIDATION

The surficial till of the county is oxidized to a brownish-yellow color. The oxidized till grades downward to an unoxidized till that is blue gray to blue black. The depth of the oxidized zone ranges from less than 10 feet to more than 30 feet. The average thickness of the oxidized till is probably about 18 to 20 feet in areas of low relief. No orderly variation in the average depth of oxidation was recognized that would aid in the identification of separate surficial tills.

---

[16] These sediments were not mapped in detail during the course of this study.

STONE COUNTS

Table 2 shows the types of pebbles recognized in deposits of till at a number of sites in Stutsman County (also see pl. 1). One thousand six hundred fifty pebbles were identified at 15 locations. No orderly variation that would serve to differentiate separate tills on the basis of pebble lithology was recognized in the samples. This is well illustrated in samples 9a and 9b, collected from an exposure on the south side of Spiritwood Lake in the SW¼ SW¼ sec. 31, T. 142 N., R. 62 W. (table 2, pl. 1). Samples of 100 pebbles each were taken from an upper and a lower till that are separated by contorted water deposited sediments. The upper till was probably deposited by a significant readvance of the ice sheet, but the number and characteristics of its pebbles (sample 9a, table 2) are similiar to those present in the underlying older till (sample 9b, table 2).

TABLE 2. — Pebble types in surficial till

	PEBBLE ANALYSIS (PERCENT) OF SAMPLE					
Sample location number*	1	2	3	4	5a	5b
Number of pebbles in each sample	100	100	100	100	50	100
ROCK TYPE:						
IGNEOUS:	(26)	(34)	(33)	(16)	(30)	(34)
Granitic	9	19	18	10	16	22
Felsic	1	3	5	1	6	2
Mafic	14	11	9	4	8	9
Quartz	2	1	1	1	0	1
METAMORPHIC:	(4)	(4)	(6)	(1)	(6)	(6)
Gneiss	3	1	4	0	4	2
Schist	1	1	0	0	0	0
Quartzite	0	2	2	1	2	4
SEDIMENTARY:	(70)	(62)	(61)	(83)	(64)	(60)
Carbonates	47	47	41	58	32	44
Shale	19	10	12	17	26	11
Sandstone	2	2	3	0	2	1
Concretions	2	1	3	6	2	3
Chert	0	2	2	2	2	1
Total	100.0	100.0	100.0	100.0	100.0	100.0

* *Locations where pebble counts were completed (pl. 1)*

1. NE¼ SE¼ SE¼ sec. 20, T. 140 N., R. 68 W.
2. SW¼ SW¼ SE¼ sec. 4, T. 140 N., R. 68 W.
3. SE¼ SW¼ NE¼ sec. 6, T. 139 N., R. 69 W.
4. NW¼ sec. 2, T. 139 N., R. 68 W.

5a. NW¼ NE¼ sec. 6, T. 139 N., R. 67 W.
5b. NW¼ NE¼ sec. 6, T. 139 N., R. 67 W.

TABLE 2. — Continued

	PEBBLE ANALYSIS (PERCENT) OF SAMPLE					
Sample location number*	6	7	8	9a	9b	10
Number of pebbles in each sample	100	100	100	100	100	100
ROCK TYPE:						
IGNEOUS:	(20)	(33)	(36)	(25)	(23)	(27)
Granitic	12	23	13	13	17	16
Felsic	0	0	3	2	1	1
Mafic	6	10	18	6	3	10
Quartz	2	0	2	4	2	0
METAMORPHIC:	(9)	(2)	(2)	(5)	(1)	(4)
Gneiss	4	0	1	3	1	1
Schist	0	1	0	0	0	0
Quartzite	5	1	1	2	0	3
SEDIMENTARY:	(71)	(65)	(62)	(70)	(76)	(69)
Carbonates	55	49	39	48	49	40
Shale	15	2	18	14	22	26
Sandstone	0	1	2	4	2	2
Concretions	1	8	1	2	2	0
Chert	0	5	2	2	1	1
Total	100.0	100.0	100.0	100.0	100.0	100.0

*6. NE¼ SE¼ SE¼ sec. 17, T. 140 N., R. 67 W.
7. SE¼ NW¼ sec. 22, T. 140 N., R. 67 W.
8. NE¼ SE¼ sec. 23, T. 140 N., R. 64 W.
9a. SW¼ SW¼ sec. 31, T. 142 N., R. 62 W.
9b. SW¼ SW¼ sec. 31, T. 142 N., R. 62 W.
10. NE¼ sec. 3, T. 138 N., R. 64 W.

	PEBBLE ANALYSIS (PERCENT) OF SAMPLE					
Sample location number**	11	12	13	14	15	Average for County
Number of pebbles in each sample	100	100	100	100	100	1650
ROCK TYPE:						
IGNEOUS:	(32)	(31)	(32)	(26)	(30)	(28.7)
Granitic	18	17	16	16	19	16.1
Felsic	5	3	3	1	1	2.2
Mafic	7	6	12	9	9	8.9
Quartz	2	3	1	0	1	1.4
METAMORPHIC:	(2)	(4)	(3)	(4)	(2)	(3.8)
Gneiss	1	1	0	2	1	1.7
Schist	0	2	1	0	0	0.4
Quartzite	1	1	2	2	1	1.8
SEDIMENTARY:	(66)	(65)	(65)	(70)	(68)	(67.5)
Carbonates	48	43	46	49	44	45.8
Shale	17	18	18	17	20	16.6
Sandstone	1	1	0	1	2	1.5
Concretions	0	2	1	2	2	2.2
Chert	0	1	0	1	0	1.3
Total	100.0	100.0	100.0	100.0	100.0	

**11. SE¼ SE¼ sec. 4, T. 140 N., R. 62 W.
12. SW¼ SW¼ sec. 28, T. 142 N., R. 63 W.
13. NW¼ NW¼ sec. 12, T. 138 N., R. 63 W.
14. SW¼ SW¼ NW¼ sec. 29, T. 139 N., R. 62 W.
15. NE¼ NE¼ sec. 17, T. 139 N., R. 63 W.

TABLE 3. — Boulder Analysis[1]

ROCK TYPE	Per cent
IGNEOUS:	(54)
Granitic	43
Basic Igneous	10
Felsic	1
METAMORPHIC:	(21)
Gneiss	13
Schist	2
Quartzite	6
SEDIMENTARY:	(25)
Carbonate	20
Shale	0
Sandstone	5
Conglomerate	0
Total	100

[1] 200 boulders sampled

Sample Site: north face of Jamestown Dam, NW¼ sec. 24, T, 140 N., R. 64 W.

In exposures that were sampled, sedimentary pebbles consisting mainly of carbonates and shale are most common followed by igneous and metamorphic stones. Many of the shale pebbles and some of the igneous and metamorphic stones are highly weathered. Carbonate pebbles seldom showed the effects of weathering. The degree of weathering of pebbles, however, does not seem to be sufficiently diagnostic to provide a sound basis for differentiating separate surficial tills.

The writer estimates that cobbles and boulders constitute less than one per cent of the till. No apparent orderly variation in the cobbles and boulders was observed in the surficial till. However, boulders are generally more common on the surface in rugged morainal topography or along the walls of stream valleys than in areas of low local relief, such as ground moraine.

Identification of 200 boulders, collected from nearby areas of ground moraine, on the north side of the Jamestown Dam just north of Jamestown reveals that 54 per cent are igneous, 25 per cent sedimentary, and 21 per cent metamorphic (table 3). Apparently, crystalline boulders are more common in the till than sedimentary boulders, and sedimentary pebbles are more common than crystalline pebbles.

LIGNITE WITHIN TILL

Chips of lignite are common in the surficial till in the county. The lignite, which is best seen in fresh exposures, is poorly consolidated, and in man-made excavations the material often shows as black smears produced by the digging instrument. The most probable source of the lignite is the Tongue River Formation of Paleocene age. This formation underlies the glacial drift and crops out at places west and northwest of the county. No orderly variation in the distribution of lignite chips in the surficial till was recognized in the county.

GRAIN-SIZE ANALYSES OF TILL

During the course of this study it became apparent that separate and distinct surficial tills could not be recognized on the basis of the characteristics described above. After most of the mapping was completed, more than 50 sites were selected for collection of samples of the till (pl. 1). The distribution of grain sizes in each sample was determined by the use of a specially designed hydrometer. The data were plotted on graphs and triangular diagrams to show similarities and differences between till samples.

With the exception of samples from the Kensal moraine and its associated landforms, the mean-size curves of samples from each of the major landform divisions in the county do not vary greatly (figs. 8, 9, 12, 13, 14, 15, and 17). Within a group of samples associated with certain landforms, however, there may be significant variations in the distribution of grain sizes. Following is a discussion of the similarities and differences in the distribution of grain sizes within and between groups of till samples associated with major landforms in the county.

Till Samples From Hummocky Stagnation Moraine. —Eleven samples of till were collected from hummocky stagnation moraine of low elevation and high

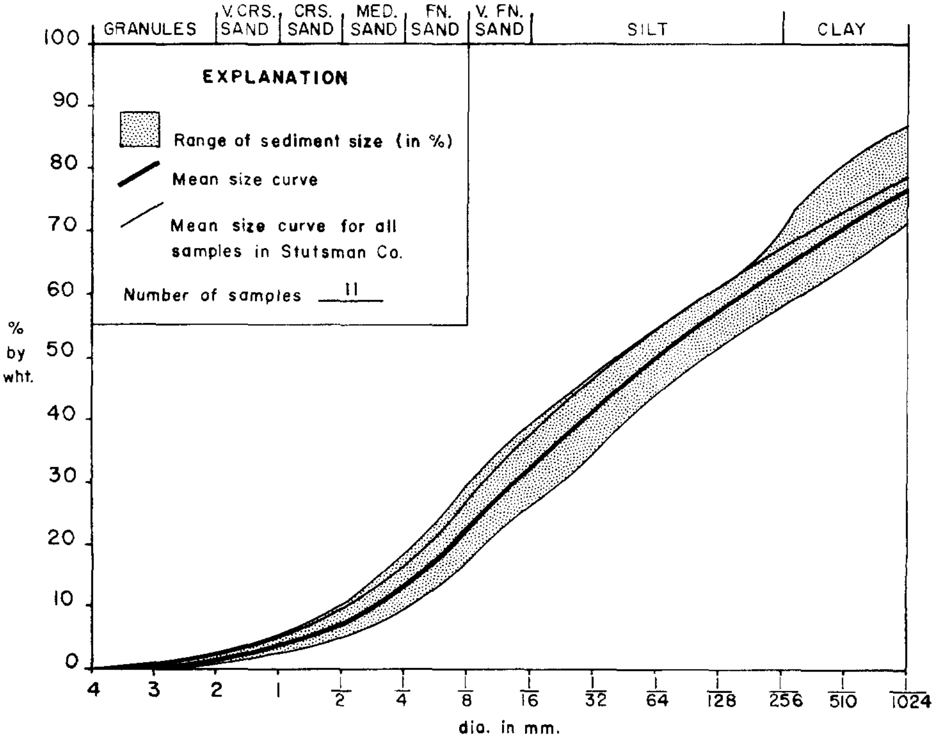


FIGURE 8—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till collected from stagnation moraine of low elevation and high relief.

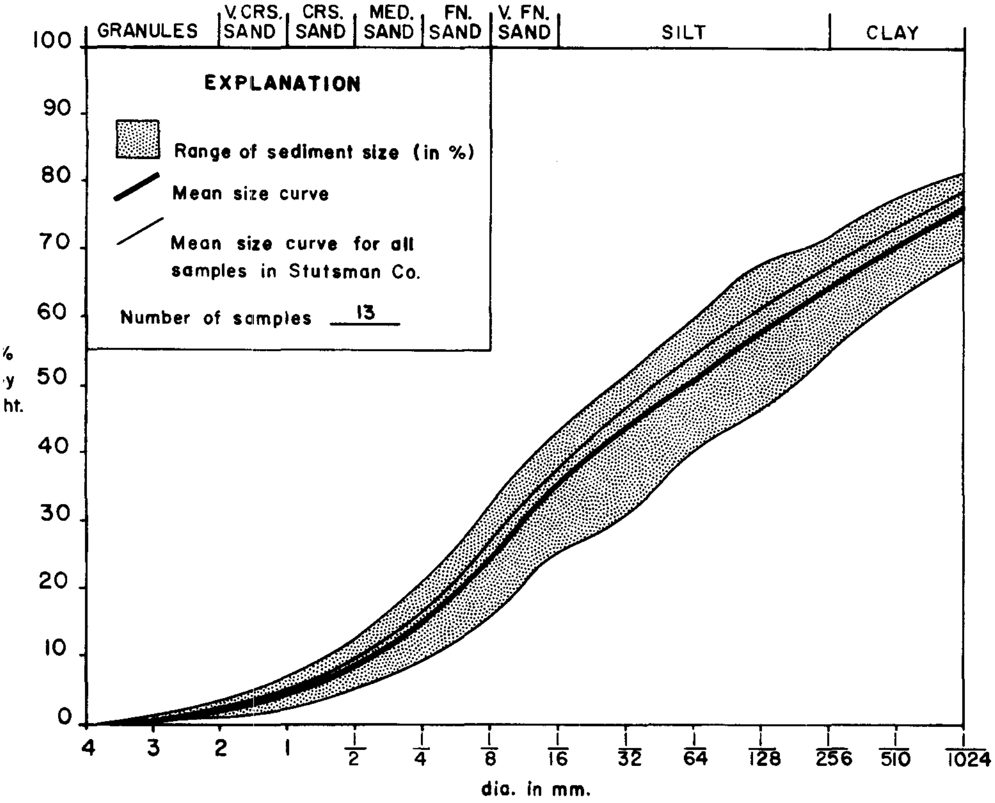


FIGURE 9—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till collected from stagnation moraine of high elevation and high relief.

relief and thirteen samples were collected from hummocky stagnation moraine of high elevation and high relief (figs. 8 and 9 and pl. 1). Figures 8 and 9 show that the mean-size curves of both groups of samples are similiar. In addition, the mean-size curves of both groups fall below the mean-size curve of all samples collected in the county. This indicates that, on the average, till samples from both types of hummocky stagnation moraine contain less coarse material than does the average of all the samples collected.

Figure 10 shows the relation between certain grain-size groups in samples from both types of hummocky stagnation moraine. Although all samples fall within a small area on the triangular diagram, apparently there is a greater variation in grain size in samples from hummocky stagnation moraine of high elevation and high relief than there is in samples from hummocky stagnation moraine of low elevation and high relief. The reason for the different degrees of dispersion in the two groups of samples is not known, but a somewhat similiar relation exists between all samples of till that were collected from ground moraine and end moraine in the east part of the county (fig. 11).

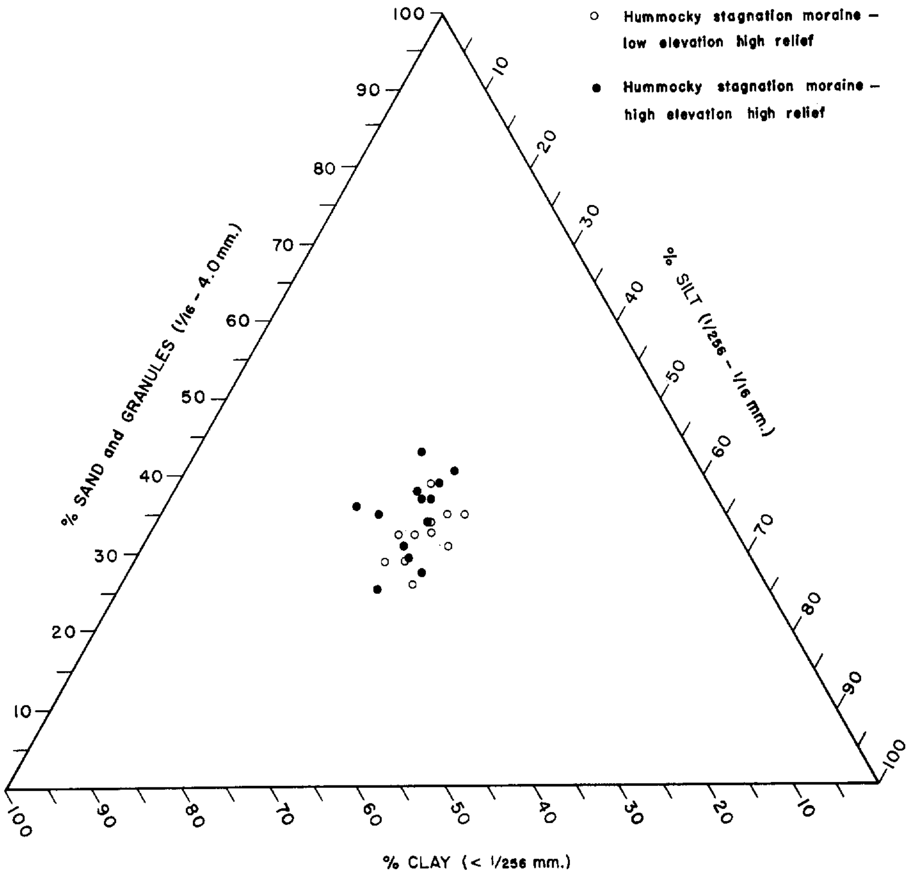


FIGURE 10—Triangular diagram showing the size and dispersion of samples of till collected in areas of stagnation moraine.

Till Samples From The Millarton, Eldridge, Buchanan And Grace City Moraines And Their Associated Landforms. — The ranges and means of grain sizes in till samples that were collected from the landforms mentioned above are shown in figures 12, 13, 14, and 15. In all groups the mean-size curves do not vary greatly from the mean-size curve of all the samples collected in the county. Figure 16, a triangular diagram based on certain grain-size groupings, shows the relation and variation within and between the till samples from the several end moraines and their related landforms. This figure reveals that, with the exception of one sample from the Millarton moraine, all the samples fall within a small area of the triangle, and any one group cannot be definitely distinguished from another on the basis of grain-size distribution.[17] A comparison of figures 10 and 16 indicates that samples of till from hummocky stagnation moraine may contain more clay and less sand and granules than do till samples from end moraines and their associated landforms, but the amount of dispersion is somewhat similiar.

---

[17] Note that till samples from the Kensal moraine and associated landforms are not included in this discussion.

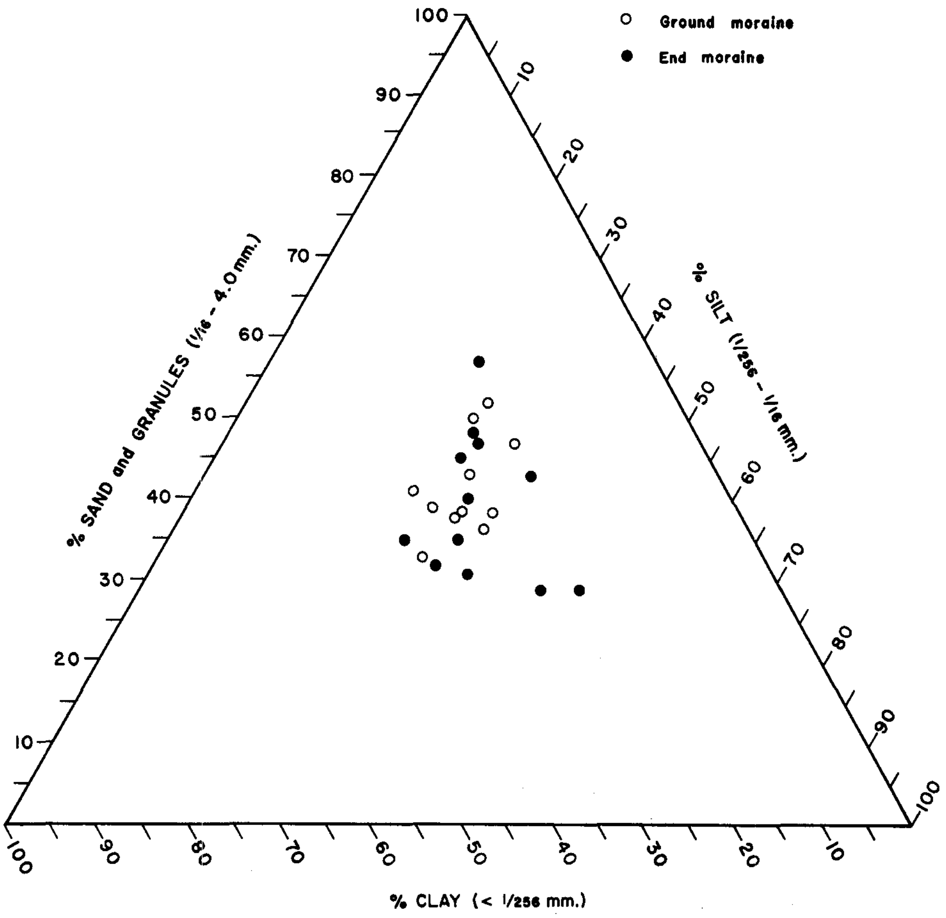


FIGURE 11—Triangular diagram showing the size and dispersion of samples of till collected in areas of end moraine and ground moraine in the east part of the county.

Till Samples From The Kensal Moraine And Its Associated Landforms. — The range and mean-size curve of nine till samples from the Kensal moraine and its associated landforms are shown in figure 17. The mean-size curve of the samples is well above the average-size curve of all the samples collected in the county. This indicates that, on the average, the samples collected from the Kensal moraine and its related landforms contain larger amounts of coarse sediments than does the average of all samples collected. Figure 16 shows that there is considerable variation within this group of samples and that some of the samples fall within the area of the triangle that contains other till samples from different groups described previously.

Summary Of Grain-size Analyses. — With the possible exception of samples collected from the Kensal moraine and its related landforms, the distributions and

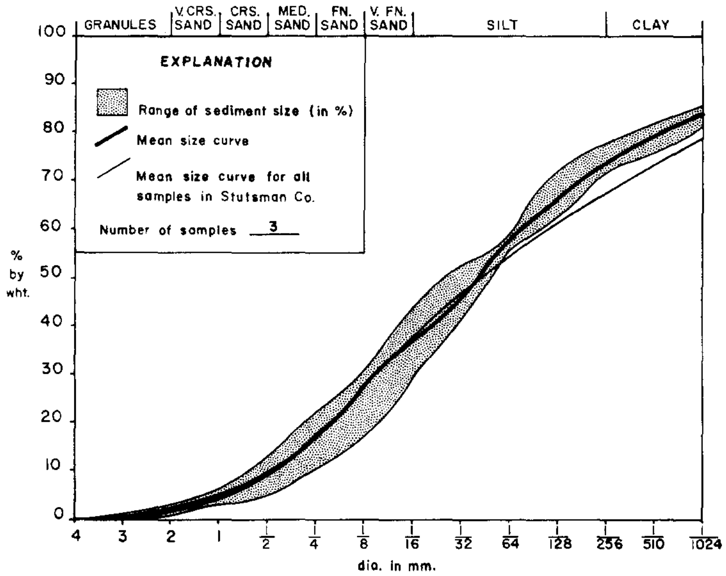


FIGURE 12—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till from the Millarton moraine and associated ground moraine.

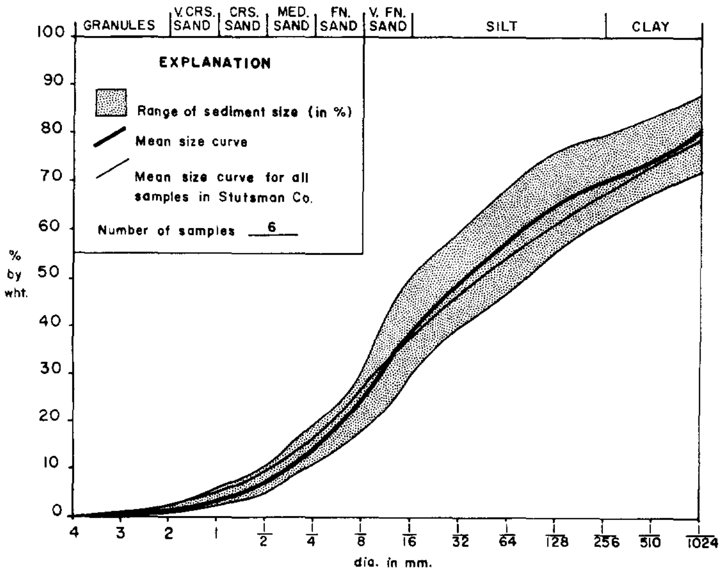


FIGURE 13—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till from the Eldridge moraine and associated ground moraine.

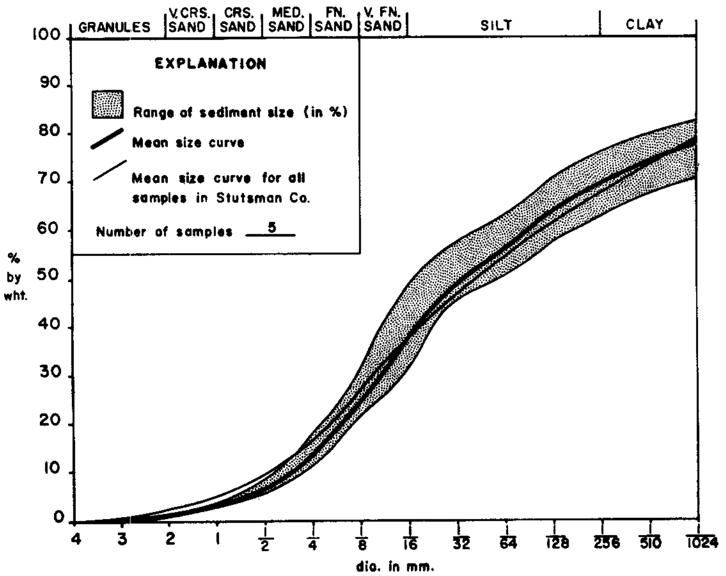


FIGURE 14—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till from the Buchanan moraine and associated ground moraine.

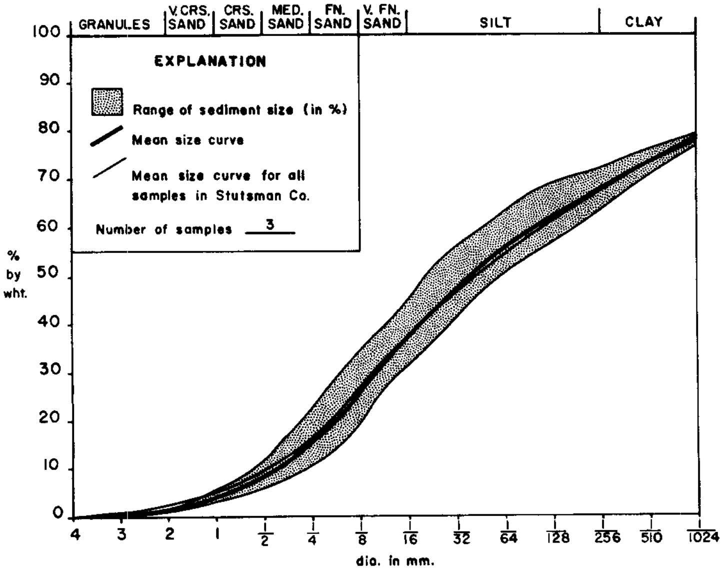


FIGURE 15—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till from the Grace City moraine and associated ground moraine.

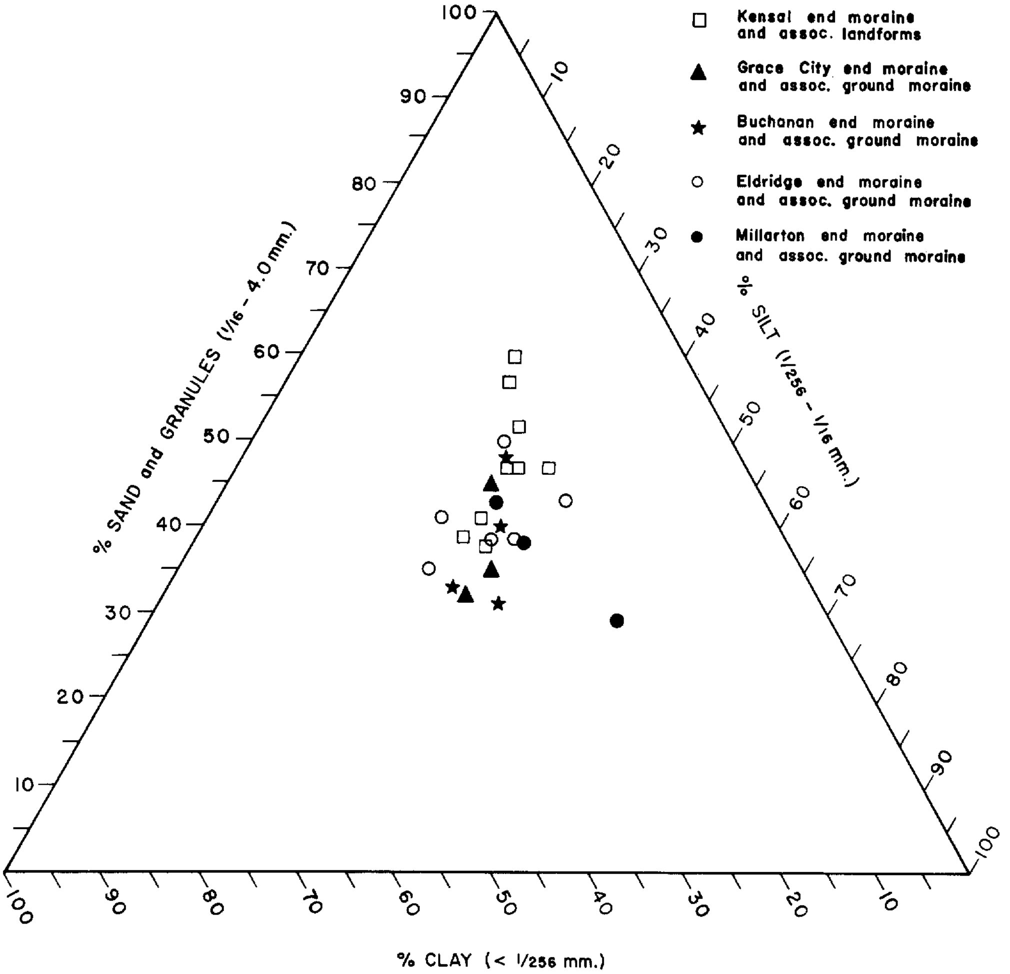


FIGURE 16—Triangular diagram showing grain size and dispersion samples of till from various morphostratigraphic units in the east part of the county.

grain sizes in samples of till collected from major landform divisions in the county do not provide a basis for differentiating separate and distinct surficial tills. However, on the basis of the samples collected, the till in the west part of the county contains greater amounts of clay and lesser amounts of sand and granules than does the till in the east part. Furthermore, when viewed as a group, the distribution of grain sizes in samples collected from the Kensal moraine and its related landforms varies somewhat from that of both nearby groups of samples and from the mean-size curve of all the samples collected. However, distinct and abrupt changes in the grain sizes in the till samples do not exist, and, if the samples are representative, they may indicate a transitional facies change in the surficial till.

SUBSURFACE GLACIAL DRIFT

The thickness of the glacial drift varies greatly throughout Stutsman County. The drift is generally thinnest in the east part of the county in areas where there are bedrock highs (pl. 2). Examples of this may be seen clearly in cross sections A-A' (test hole 1873, 1928b), B-B' (test holes 1805, 1806), G-G' (test hole 1351), and K-K' (test hole 1884) (pl. 4). In general, the drift is much thicker in the west than it is in the east, but throughout the county the greatest thicknesses of drift are where deep valleys in the bedrock surface have been filled with glacial drift.

VARIATIONS IN THE THICKNESS OF GLACIAL DRIFT BETWEEN THE EAST AND WEST PARTS OF THE COUNTY

An indication of the large amount of subsurface glacial drift in the west part of the county as compared with the east part is shown on cross sections A-A', B-B', C-C', and D-D'. The bedrock surface in cross section A-A' shows no major increase in altitude to the west; in cross sections B-B' and C-C' there is only a slight rise in the altitude of the bedrock surface to the west. In cross section D-D' the altitude of the bedrock surface increases considerably to the west, but this is probably related to an isolated bedrock high located in the southwest part of the county (pl. 2). The topographic profiles of the same cross sections, however, show a marked increase in altitude from east to west. In some instances, the altitude of the topography increases from about 1,500 feet in the east part to more than 1,900 feet in the west part of the county. The higher altitudes of the topography in the west are largely the result of increased thickness of the glacial drift.

GLACIAL DRIFT ASSOCIATED WITH BEDROCK VALLEYS

An example of large amounts of glacial drift associated with a valley cut into bedrock is shown in the east parts of cross sections A-A' (test holes 1872, 1874, 1928b, 1928c) and G-G' (test holes 1364, 1594). Both cross sections show part of the Spiritwood Valley system. The valley is eroded into bedrock and later filled with more than 500 feet of drift. The bedrock valley was probably formed by a north-flowing preglacial stream. This interpretation is suggested by the presence of exceptionally thick deposits of water-deposited sediments and the absence of till in the lower part of the buried valley. If a glacier had advanced from the north, it would have blocked the north-flowing stream and formed a lake in the river valley. Sediments, mainly silt and clay, would probably have been deposited in the ponded water. With the subsequent approach of the ice margin coarser sediments would probably have been deposited, and finally, as the glacier overrode the bedrock valley and the sediments that were deposited in it, the valley would have been filled with glacial till. The logs of test holes drilled in the Spiritwood Valley indicate a similiar sequence of depositional events and support this interpretation.

Another example of the increase in thickness of glacial drift in an area where there is a bedrock valley is shown in cross section C-C' (test hole 1582) and D-D' (test hole 1748). This bedrock valley, which trends northwest-southeast, is not as deep as Spiritwood Valley and is filled largely with till and some coarse outwash (pl. 2). The types of glacial drift within the bedrock valley indicate that probably the depositional environment and history associated with the valley was somewhat different from that of the Spiritwood Valley.

AGE OF THE SUBSURFACE GLACIAL DRIFT

Though the glacial history of North Dakota is not well known, apparently multiple glaciation occurred and all but the southwest part of the state was glaciated at least once. Numerous test-hole logs record two or more bodies of till in the subsurface that are separated by other types of glacial drift, such as clay, silt, sand and gravel. Examples of this may be observed on the following cross sections: A-A' (test holes 1823, 1890, 1926), C-C' (test holes 1333, 1362, 1561, 1590), D-D' (test holes 1744, 1760, 1764, 1765), E-E' (test holes 1340, 1341), F-F' (test holes 1546, 1558), K-K' (test hole 1725), and L-L' (test hole 1901). These sequences of deposits suggest that the glacier overrode the area more than twice, but, even if this were the case, it is not possible to determine the length of the time interval between periods of glaciation from the information available in test-hole logs.

In some instances, logs of several test holes drilled in the same general area of the county show masses of till separated by varying thicknesses of other types of glacial drift. Furthermore, more than two separate masses of till are recorded in each of the test-hole logs. This is especially well illustrated in test holes 1809, 1810, 1811, 1812, 1813, 1814 and 1815, shown on cross section B-B'. The similiar stratigraphy recorded for each of these test holes, coupled with their proximity, strongly suggests that glaciers overrode the area more than twice to deposit separate masses of till. Again, however, it is not possible to determine the length of a time interval that elapsed between separate phases of glacial activity.

Certain test-hole logs indicate the presence below the surface of cemented or partially cemented glaciofluvial material that may overlie uncemented glacial drift or bedrock. Cemented zones are shown in cross sections B-B' (test holes 1801, 1814), C-C' (test holes 1348, 1363), and F-F' (test hole 1552). In test hole 1552, a cemented gravel overlies an oxidized zone within an underlying till. The presence of cemented or partially cemented drift in the subsurface suggests an ice-free period and possibly an inter-glacial stage or substage. Paulson (1952, p. 28-29) describes "cemented gravel" beneath the surface in the vicinity of Streeter, North Dakota, and suggsts that it may be pre-Wisconsin in age. Some or all of the cemented glaciofluvial sediments described are possibly the same age as the cemented gravel described by Paulson, but no basis for correlation exists at this time.

In one test-hole log (test hole 1892, NE cor. sec. 18, T. 143 N., R. 68 W.) at depths of 272 to 294 feet and again from 337 to 367 feet below the surface, masses of yellowish-orange oxidized till are interbedded with olive-gray unoxidized till. The oxidized till may be inclusions of an older weathered till within younger glacial drift or represent the uppermost weathered zone of two older deposits of till.

An oxidized zone within the upper part of a buried till indicates that an ice-free period of significant duration must have occurred to permit the weathering. For example, the surficial till in the county has been oxidized to an average depth of about 20 feet since the margin of the glacier has retreated from the area. However, in the test hole described above, the original thickness of the buried oxidized zone (or zones) is not known because the weathered drift is intermingled with unoxidized till and thus an estimate of the time that the area was free of ice to permit the oxidation of the till cannot be made.

In several test-hole logs oxidized zones have been identified within till at considerable depths below the surface. These oxidized zones are shown on cross sections A-A' (test holes 1922, 1927) and F-F' (test holes 1552, 1554). The logs of test holes 1922 and 1927 indicate that both oxidized zones are 10 feet thick and probably represent weathering in the uppermost part of a till unit that directly overlies bedrock. Both oxidized zones are overlain by more than 375 feet of younger glacial drift. A slightly oxidized zone, described as 8 feet thick, is noted in the log of test hole 1554; it is overlain by 347 feet of younger drift. The log of test hole 1552 indicates that a slightly oxidized till was present also at a depth of 126 feet, but the thickness of this zone is not recorded. The till unit in which the oxidized material is recognized is about 225 feet thick and is underlain by a cemented gravel. The oxidized zones described above may record one or more interglacial stages or substages, or a combination of both. It is not possible, however, to determine whether or not they record more than one ice-free period of significant duration. The thickness of the oxidized zones does not necessarily indicate the length of the ice-free period because some of the oxidized till could have been removed and incorporated in younger glacial drift during later glacial events, or, though not very probable, later glacial activity could have deposited larger amounts of oxidized till in certain locales. It is safe to conclude, however, that the oxidized till in the subsurface records one or more periods of significant duration during which the area was free of glacial ice.

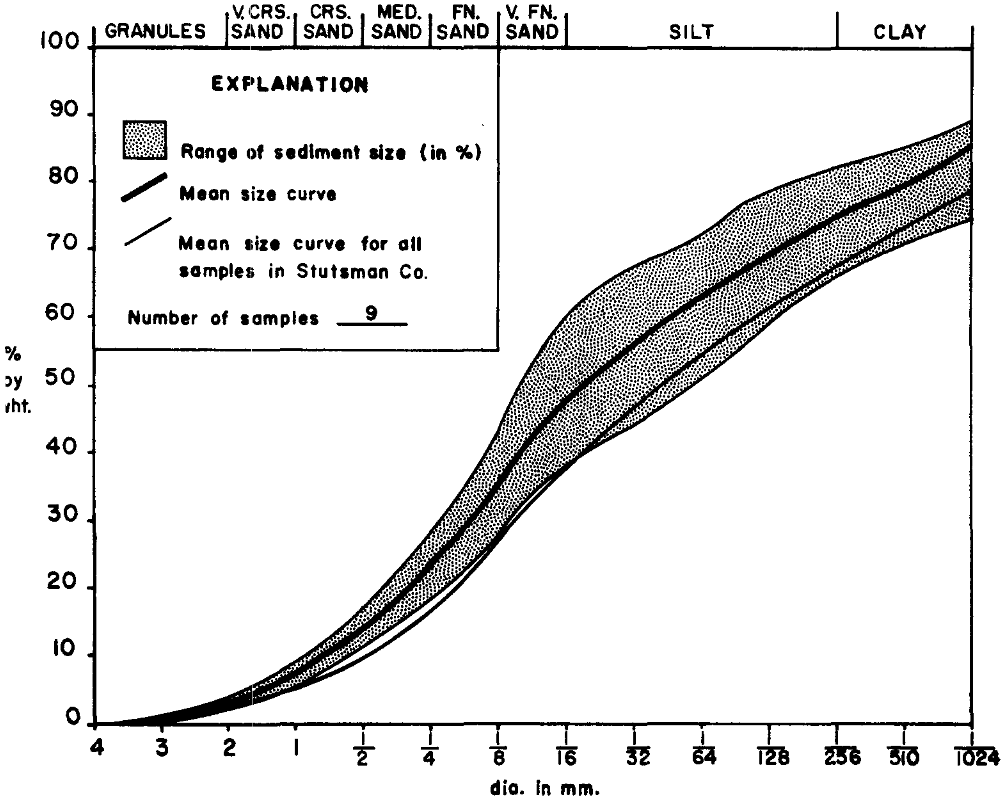


FIGURE 17—Cumulative curves showing the distribution of particles smaller than 4 mm. in samples of till from the Kensal moraine and associated landforms.

In test hole 1903 shown in cross section G-G', wood fragments were recovered from a deposit of fine to coarse gravel between a depth of 68 to 73 feet. The gravel layer is overlain by 62 feet of drift consisting mainly of till. One hundred sixty-seven feet of till, 31 feet of gravel, and bedrock, in turn, underlie the wood-bearing gravel. The Geochronology Laboratory of the U. S. Geological Survey completed a radiocarbon age determination on samples of the wood fragments. They were dated at more than 38,000 B.P. (Sample W-1020). This suggests that the gravel in which the wood is found, the underlying till, and the basal gravel were all deposited some time during Pleistocene time prior to 38,000 years ago.

In conclusion, abundant evidence indicates that drift significantly older than the surficial drift is present below the surface in Stutsman County. However, the actual age or ages of the underlying drift are not known at this time. The radiocarbon date on wood fragments in a buried gravel deposit and oxidized zones in the till at considerable depths below the surface indicate that some of the subsurface drift was deposited during one or more earlier stages of glacial activity; the earlier stages may have been separated from the last period of glacial activity by a considrable period of time. Thus, it is reasonable to conclude that early Wisconsin and (or) pre-Wisconsin drift exists in the subsurface in the county.

GLACIAL LANDFORMS AND THEIR HISTORY

Two distinctly different groups of landforms are present in Stutsman County. The first group, associated with the Drift Prairie, was formed by an active glacier that was not characterized by extensive stagnation. The second group, associated with the Coteau du Missouri in the west part of the county, was produced mainly from an ice sheet that was characterized by extensive stagnation.

Certain glacial landforms in the county may be interpreted on the basis of their form and distribution as morphologic units (Am. Geol. Inst., Supplement, 1960, p. 43) or as morphostratigraphic units (Frye and Willman, 1960, p. 7-8; Frye and Willman, 1962). The last deglaciation may be interpreted on the basis of morphostratigraphic units rather than the character of the drift (e.g., rock stratigraphic units). Though this procedure has certain disadvantages, it is used in this study because differences in the character of the till in the county are difficult to recognize. Discussions of morphostratigraphic units include statements regarding the nature of the associated drift.

LANDFORMS OF THE COTEAU DU MISSOURI

In North Dakota the area associated with the east margin of the Missouri Plateau, between the Missouri Escarpment and the Missouri River, that is characterized by morainal topography, is generally known as the Coteau du Missouri, or informally as the Missouri Coteau. Though the exact nature and boundaries of the Coteau du Missouri are in question (see Howard, 1960, p. 8-9), most of the landforms in the west part of the county may be included in this area. The landforms of the Coteau du Missouri in Stutsman County consist of the rugged morainal topography that lies between the Missouri Escarpment and the west border of the county.[18] In this rugged morainal topography two morphostratigraphic units are recognized — the Streeter moraine and an extensive area comprised of various landforms that resulted from stagnation of the ice sheet.

STREETER MORAINE

According to Paulson, (1952, p. 17), the Streeter moraine (Lemke and Colton, 1958, p. 49, fig. 5) represents a part of the Gary moraine named by Chamberlin (1883, p. 293). It is an end moraine that trends north through south-central North Dakota, but only a small part of the proximal margin is located in secs. 30, 31, and 32, T. 137 N., R. 68 W., in the extreme southwest corner of Stutsman County (pl. 1). Paulson (1952, p. 17-21) recognizes two strikingly different types of topography associated with the moraine. The first is a belt of morainic topography consisting of nearly parallel ridges (fig. 6). The ridged belt ranges generally from 1 to 3 miles in width and is characterized by minor reentrants. The second consists of knob and kettle topography located east, or on the proximal margin, of the ridged end moraine. The writer agrees with Paulson's interpretation of the ridged end moraine but interprets the knob and kettle topography to be associated with hummocky stagnation moraine (fig. 6). In this report the part of the Streeter moraine that is located within Stutsman County includes the topographic high associated with the ridged end moraine but does not include the knob and kettle topography on its proximal margin.

In Stutsman County the Streeter moraine is a well-defined, rugged linear topographic high, characterized by an irregular crest that rises above an extensive tract of hummocky stagnation moraine to the east. The moraine consists mainly of till that is probably equivalent of the Streeter drift described by Rau (1962, p. 28-35).

INTERPRETATION. — Lemke and Colton (1958, p. 49-50, fig. 3) believe that the moraine was formed some time after the Cary maximum and that it may be

---

[18] This description applies only to the landforms in Stutsman County and is not intended to describe the nature of the Coteau du Missouri in all of North Dakota.

correlated with the B-1 readvance of Mankato time recognized by Flint (1955, fig.31) in South Dakota. The Streeter moraine is interpreted to have marked a significant still-stand of an ice margin, but it may not represent a significant glacial readvance in North Dakota (Rau, *et. al.*, 1962, p. 35; Clayton, oral communication, 1961).

POST-STREETER LANDFORMS WEST OF THE MISSOURI ESCARPMENT

Various landforms, some resulting from extensive stagnation of an ice sheet, are found between the Missouri Escarpment and the proximal margin of the Streeter moraine on the west border of the county. The landforms that are known to be associated only with extensive glacial stagnation are hummocky stagnation moraine, perched lacustrine plains, and various stagnation outwash forms. In addition, eskers, kames, kame complexes and kettle chains are present.

HUMMOCKY STAGNATION MORAINE. — Hummocky stagnation moraine covers much of the west part of the county but does not extend east of the Missouri Escarpment. The unit extends over more than 400 square miles in the area described in this report and undoubtedly is present extensively in other parts of the Coteau du Missouri in North Dakota.

Hummocky stagnation moraine is similiar, if not identical, to "hummocky disintegration moraine" or "hummocky dead-ice moraine" described by Gravenor and Kupsch (1959, p. 50-52). The writer believes that the term "hummocky stagnation moraine" is most appropriate because active ice may experience disintegration and "dead-ice" implies that the ice was not active at any time during the process of landform development. The term "stagnant" does not mean that the ice could not experience movement, but rather that the ice was stationary, whether capable of movement or otherwise.

In areas of hummocky stagnation moraine local relief may range generally from 20 to 200 feet per square mile. Closed depressions, ranging from angular to well rounded in plan and varying greatly in size, are abundant (fig. 7). Ice-contact faces are common on the flanks of the closed depressions, which indicates that they were formed, at least in part, by melting of buried ice blocks. The depressions are separated by rugged morainal hills that consist mainly of till and that vary greatly in size and height. As stated previously, Gravenor and Kupsch (1959, p. 50) describe a similiar landscape in Canada as a "non-descript jumble of knolls and mounds of glacial debris separated by irregular depresssions." There is a notable absence of an integrated surficial drainage system within areas of hummocky stagnation moraine. As a result, lakes and marshes, locally called "potholes", are common.

Hummocky stagnation moraine lacks the overall and internal linear pattern that is associated with end moraine. The average altitude of hummocky stagnation moraine in the county is lower than the crest of the Streeter moraine but higher than the landforms of the Drift Prairie to the east. The local relief is much greater than that which is found in areas of ground moraine in the county. In addition, other landforms, made up of glaciofluvial and glaciolacustrine sediments that formed as a result of extensive stagnation, are present in or along the margin of the hummocky stagnation moraine. These landforms are not present in either ground moraine or end moraine.

In Stutsman County two mappable units of hummocky stagnation moraine, differentiated on the basis of average altitudes and height, may be recognized. These units are referred to in this report as hummocky stagnation moraine of relatively high altitude and high relief (Qsh, pl. 1) and hummocky stagnation moraine of relatively low altitude and high relief (Qsl, pl. 1). These descriptive terms were adopted in order to avoid precise genetic implications and yet give an accurate portrayal of the landscape. Hummocky stagnation moraine of low altitude and high relief is generally between 1,750 and 1,850 feet above sea level; hummocky stagnation moraine of high altitude and high relief is generally more than 1,850 feet above sea level. Maximum altitudes exceed 2,000 feet above sea level in many places in the county (pl. 3). No well-defined, orderly pattern is associated with either unit. Rather, the variation in altitude probably resulted from differential deposition. Areas of hummocky stagnation moraine of high altitude and high local relief are well shown in the vicinity of Woodworth, along Interstate Highway 94 between Cleveland and Medina, and in the vicinity of Streeter. Hummocky stagnation moraine of low altitude and high relief is well shown in the Vashti area and in the area between Windsor and Cleveland.

Kames and eskers may be present in both units of hummocky stagnation moraine. However, kames in areas of hummocky stagnation moraine are difficult to recognize because the landforms are similiar to the numerous mounds of till. All kames shown on plate 1 consist of sand and gravel. Other kames may exist that were not recognized during the course of this study. At least three small eskers are found in areas of hummocky stagnation moraine in the county, but they are neither prominent nor extensive landforms.[19]

Locally, surficial stringers of sand and gravel and gravel-capped hills that lack a distinct topographic expression are common in areas of hummocky stagnation moraine. Many hillocks capped with 1 to 5 feet of gravel are found in secs. 3 and 4, T. 140 N., R. 69 W., several miles northwest of Medina. Deposits of this nature, referred to as undifferentiated glaciofluvial deposits, are shown on plate 1 only if they are found continuously over a large area.

Hummocky stagnation moraine probably formed in association with glacial ice that was disintegrating in place rather than from active ice possessing a margin that was retreating in an orderly fashion. This interpretation accounts for the lack of linear trends in the morainal topography and is supported by the presence of the additional stagnation forms described below. The mode of origin of the knob and kettle topography of hummocky stagnation moraine, however, is subject to question. The knobs may be the result of: 1) Ablation till slumping into openings on the surface of the ice, 2) basal till being squeezed up into openings at the base of the ice, or 3) a combination of both processes. (For discussion, see Gravenor and Kupsch, 1959, p. 56-60; Stalker, 1960; among others.) Squeezing of basal till may have been important in molding the landscape, but the process cannot account for perched lacustrine plains and some stagnation outwash forms described below. These forms and their associated sediments indicate that debris carried by the glacier could not have been restricted to the basal portion of the stagnating ice.

It is important to note that ablation drift may accumulate on the surface of a glacier through thinning of the ice sheet. If, previous to stagnation, the advancing ice was characterized by large-scale shearing resulting in the overriding of underlying ice in the area presently known as the Coteau du Missouri, glacial drift could have been deposited upon underlying ice along the shear zone. This could have resulted in significant concentrations of englacial debris. Thinning of the ice sheet could have resulted in the accumulation of large amounts of ablation drift on the surface of the disintegrating glacier. The problem is complicated by the fact that there is no apparent vertical variation in the character of the till associated with hummocky stagnation moraine. As a result, basal till cannot be distinguished from ablation till if, in fact, both exist.

PERCHED LACUSTRINE PLAINS. — Perched lacustrine plains are present in and bordering hummocky stagnation moraine. Similiar landforms have been called "moraine plateaus" (Hoppe, 1952, p. 5; Gravenor and Kupsch, 1959, p. 50-51) and "dead-ice plateaus" (Stalker, 1960a, p. 5-11). If these terms refer to the same landform, the writer believes that the term "perched lacustrine plain" is most appropriate because the landforms: 1) Do not necessarily resemble plateaus; 2) are commonly capped by lacustrine sediments, rather than till or glaciofluvial material associated with moraines; and 3) may have been formed, at least some time during their development, in association with stagnant ice rather than with dead ice.

---

[19] The eskers are in sec. 19, T. 137 N., R. 68 W.; in sec. 34, T. 138 N., R. 68 W.; and in secs. 13 and 14, T. 140 N., R. 69 W.

The landforms are, in fact, lacustrine plains that form topographic highs which vary in altitude.

Over 20 perched lacustrine plains have been recognized in the west part of the county (Qel, pl. 1). They are within an area dominated by stagnation landforms and, viewed as a group, they do not display an organized pattern.

Perched lacustrine plains are generally characterized by low local relief, but they may lie at a slightly higher altitude than the average of the surrounding landscape. They are underlain by varying thicknesses of glaciolacustrine and possibly some glaciofluvial material or till. The plains were formed by the deposition of sediments from ponded water that was contained, at least in part, by stagnating ice. With the disintegration of the ice, the lacustrine sediments were left at higher altitudes, in general, than those of the adjacent stagnation landforms; some of the perched lacustrine plains are at relatively high altitudes.

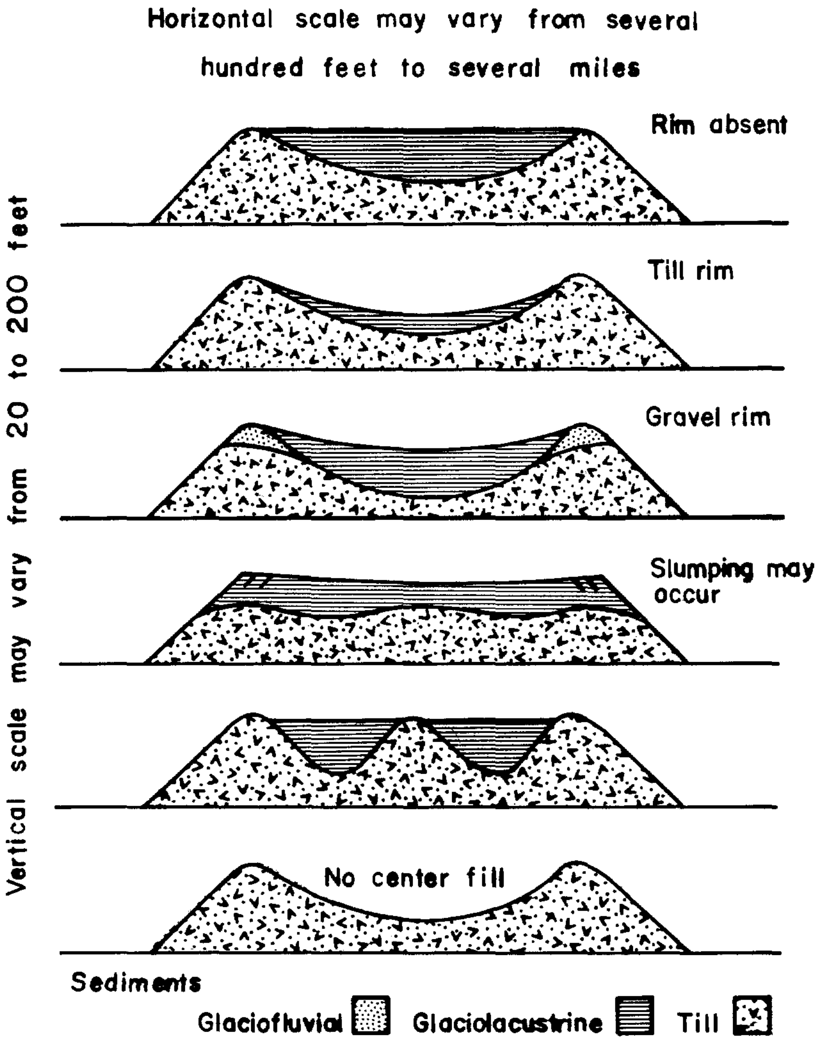
Perched lacustrine plains range in plan from circular to angular and they may have irregularly shaped appendages. In Stutsman County the long dimension of the perched lacustrine plains ranges from about 1 to 4 miles. The plains average about 2 square miles in area. Topographic profiles vary from flat-topped, steep-walled features to saucer-shaped forms with gentle outer slopes. The peripheral areas consist of glaciolacustrine sediments, glaciofluvial material, or till (fig. 18).

An example of the saucer-shaped perched lacustrine plain is located with its center in sec. 34, T. 142 N., R. 67 W. A poorly defined rim, consisting of till, forms part of the south and most of the west border. In places the rim is more than 30 feet higher than the shallow closed depression near the center. The interior part of the perched lacustrine plain is underlain by water-laid silt and clay that average about 10 feet in thickness; these sediments are underlain by till. On the northeast flank are two kame-like features with crests more than 40 feet higher than the plain.

An example of the flat-topped perched lacustrine plain is centered in sec. 5, T. 138 N., R. 68 W., about 6 miles south of Medina. The plain has an altitude about 100 feet higher than hummocky stagnation moraine on its flanks and it has no rim of glaciofluvial material or till. Silt and clay, along with small amounts of sand, are exposed on the steep north flank along a section-line road and slump structures are present in this exposure. Auger borings indicate that the lacustrine sediments that underlie the plain exceed 40 feet in thickness in some places.

A landform that resembles a perched lacustrine plain is located with its center in sec. 21, T. 140 N., R. 69 W., about 5 miles northwest of Medina. Although its surface is dominantly flat, it contains numerous pits or small closed depressions. In addition, sand and gravel rather than silt and clay, are the most common sediments associated with the form. Although these variations exist, the landform probably evolved in the same manner as a perched lacustrine plain and it is interpreted as such in this report (Qel, pl. 1); however, on the basis of its sediment characteristics, it might also be described as an ice-restricted outwash plain. The landform probably represents a transition between a true perched lacustrine plain and an ice-restricted outwash plain.

Perched lacustrine plains are present in many shapes and forms in Stutsman County. The descriptions above are examples of several types. In all cases the evidence left by the forms indicates that the disintegrating ice sheet melted in place. In this study no conclusive evidence was found regarding the origin of the depressions in which the melt water was ponded. Although Stalker (1960a, p. 30) describes varves associated with the sediments of similiar landforms in Canada, none were observed in Stutsman County. Stalker (1960a, p. 30) states that the time required for construction of similiar landforms may be measured in tens or possibly hundreds of years. The presence of Pleistocene pelecypods and gastropods in ice-contact stagnation outwash in Stutsman County strongly indicates that



IDEALIZED CROSS SECTIONS OF VARIOUS TYPES OF PERCHED LACUSTRINE PLAINS

in part after Stalker, 1960, p. 10

FIGURE 18

life existed in the stagnation environment. This suggests that disintegration of glacial ice was a slow process. If this is true, perched lacustrine plains probably formed over a significant period of time rather than rapidly.

LANDFORMS ASSOCIATED WITH STAGNATION OUTWASH MATERIALS. — Landforms composed of glaciofluvial materials deposited in a stagnation environment include: 1) pitted outwash plains, 2) ice-restricted outwash plains, and 3) ice-walled gravel trains. In addition, large and small tracts of outwash that lack distinct topographic forms are present. Small deposits of this nature are not shown on plate 1, but extensive deposits, described as undifferentiated outwash, are shown and were mapped on the basis of lithology.

PITTED OUTWASH PLAIN. — An extensive pitted outwash plain is located southwest of Woodworth along the west border of the county (T. 141 N., and T. 142 N., R. 69 W., Qpp, pl. 1). The unit represents the east part of a large outwash plain that extends westward into Kidder County. On the east the pitted outwash plain is bordered by hummocky stagnation moraine, two kame complexes, and an ice-walled gravel train. Local relief, which is estimated to exceed 30 feet per square mile, is caused by the presence of numerous pits, some more than a mile in length, that are rounded to sub-rounded in plan. In addition, there is a notable absence of an integrated surficial drainage system. The nature and location of the pitted outwash plain indicate that, at least in this area, the ice sheet was characterized by some degree of stagnation in eastern Kidder County as well as western Stutsman County.

ICE-RESTRICTED OUTWASH PLAINS. — Ice-restricted outwash plains consist of glaciofluvial sediments that were deposited over a large area in a stagnating ice environment. The sand and gravel may have been deposited upon glacial ice and superimposed upon the subglacial landscape as the underlying ice melted or may have been deposited between masses of stagnant ice. An ice-restricted outwash plain and a pitted outwash plain are similiar in mode of origin, but significant topographic differences exist. Because of the nature of their formation, ice-restricted outwash plains may occur at higher altitudes within hummocky stagnation moraine. This indicates that glacial ice must have covered the areas of hummocky stagnation moraine when the sand and gravel was deposited. Perhaps as stagnation progressed, the rate of ice disintegration decreased, resulting in decreasing amounts of glacial melt water. The decrease in the volume of melt water could be explained by a decrease in the amount of available glacial ice and by an increase in the amount of ablation drift on the surface of the ice that would act as an insulating body, slowing the rate of ablation. If this were true, it would help to explain the lack of glaciofluvial material in areas of hummocky stagnation moraine at altitudes lower than those of ice-restricted outwash plains, and it would also account for the confined, or restricted, distribution of the glaciofluvial material that makes up the ice-restricted outwash plain.

There are two large ice-restricted outwash plains in the southwest part of the county. One trends east-west in the vicinity of Medina, and the second, between Streeter and Gackle, extends in a northerly direction (Qso, pl. 1). Both consist mainly of sand and gravel. The associated topography is rugged and bears little resemblance to a true outwash plain. The glaciofluvial sediments may be found high on the flanks of hummocky stagnation moraine or may merge topographically with adjacent landforms. Possibly some of the sand and gravel was superimposed upon rugged subglacial topography. This would account for the morainal landscape associated with some areas of ice-restricted out-wash plains.

An exposure of sediments associated with an ice-restricted outwash plain is in a gravel pit at the east edge of Medina. Sand, granules, and pebbles are most abundant, but small amounts of clay and silt and scattered cobbles are present also. Slump structures are in the exposure and cross-bedding indicates that the dominant drainage direction was to the west. In addition, carbonaceous material in the deposit suggests that life existed in the stagnant ice environment. A description of the section follows:

South wall in east section of gravel pit 0.4 miles east of Medina business district in the SW¼ sec. 32, T. 140 N., R. 68 W.

Total thickness of described section: 10.5 feet.

Top	Thickness Ft	In
Soil, black with occasional pebbles		8
Well-bedded pebble sand, highly calcareous, occasional decomposed concretions and crystalline stones	1	6
Coarse sand and gravel, highly iron-stained, containing decomposed crystalline pebbles and numerous shale chips	1	4
Coarse sand with some pebbles cross-bedded and dipping west, numerous carbonaceous streaks	2	
Very fine clay and silt, gray to yellow, well-sorted, fine laminated beds	1	
Coarse gravel, horizontal beds, containing some large pebbles and small cobbles	1	
Coarse sand and pebbles cross-bedded and dipping west, highly iron-stained	1	
Covered by recent slump	4	

At two locations in the county gastropod and pelecypod shells are present in stagnation outwash. Along the north wall of a gravel pit 4 miles south of Medina (NE cor. SE¼ sec. 23, T. 139 N., R. 69 W.) several species of gastropod shells are found in gray calcareous mud that is overlain by about 1½ feet of gravel. Along the contact between the mud and an underlying gravel, pelecypod shells with concentric ribbing are common. The long axes of the shells are oriented parallel to the bedding of the sediments, but most are partially fragmented, which indicates that they may have been transported short distances.

Along the north face of a gravel pit 6 miles east-southeast of Medina (SE¼ sec. 17, T. 139 N., R. 67 W.), on the north side of the section-line road, gastropod and pelecypod shells are present in an ice-contact glaciofluvial deposit that has the form of an ice-marginal alluvial fan, or kame-like feature. Planispiral and conical gastropod shells are irregularly distributed throughout the sediments but are most common in certain sandy beds. Thin, finely ribbed pelecypod shells, ranging from very small to about 4 inches in length, are numerous along a sandy horizon that averages 1½ feet thick and is located about 4 feet above the base of the pit. The long axes of the pelecypod shells are parallel to the bedding of the sand and gravel. The condition of the shells indicates that they were not transported far, if at all, by glacial melt water.

The nature and distribution of ice-restriicted outwash plains indicate that large amounts of glaciofluvial material were deposited upon and (or) between masses of ice in the west part of the county. Subsequent melting of the glacial ice produced outwash plains that are characterized by complex topographic forms that are unlike either pitted or non-pitted outwash plains. Furthermore, evidence of life in the environment may indicate that the ice sheet disintegrated slowly rather than rapidly.

ICE-WALLED GRAVEL TRAIN. — A large gravel train that was formerly ice-walled extends southwest from the vicinity of Goldwin to join the pitted outwash plain described previously (Qso, pl. 1). The gravel train is somewhat similiar to the "ice-walled channel" described by Gravenor and Kupsch (1959, p. 55-56), but it is a depositional rather than an erosional form. Thwaites (1959, p. 46) states that the term "valley train" is more appropriate than "gravel train" in describing glaciofluvial sediments that were deposited in a pre-existing valley. In this instance, the glaciofluvial sediments were not deposited in a pre-existing valley; thus, the term "ice-walled gravel train" is appropriate, but it should not be confused with "valley train."

The ice-walled gravel train is characterized by rugged topography somewhat similiar to that of hummocky stagnation moraine. In many places it is difficult, if not impossible, to recognize the gravel train on the basis of topography alone; it must be delineated on the basis of lithology also. The northeast part of the ice-walled gravel train (sec. 31. T. 143 N., R. 67 W.) has an altitude of more than 1,900 feet above sea level. The average altitude gradually decreases to about 1,800 feet above sea level at the southwest extremity, where the form merges transitionally with a pitted outwash plain. The width of the ice-walled gravel train ranges generally from 1 to 2 miles, and averages about 1½ miles.

The landform may be flanked on both sides by hummocky stagnation moraine with a lower average altitude. In some places it trends at right angles to the dominant slope of the landscape (in sec. 13, T. 142 N., R. 68 W.), with the result that glaciofluvial materials are located on the side of a topographic high, but not at the crest or base of the hill. Coarse gravel associated with the gravel train is exposed in several pits about 3½ miles east of Woodworth (secs. 6 and 31, T. 143 N., R. 67 W.); in these pits the deposits are at least 25 feet thick. Near the southwest end of the feature, however, the coarse fraction in the fluvial material tends to be smaller. Observations in the field show a decrease in grain size in a southwest direction.

The ice-walled gravel train probably formed from deposition of glaciofluvial material in a channel bounded on both the northwest and the southeast by glacial ice. The mode of formation is somewhat similiar to that of an esker, but the gravel train is not characterized by eskerine landforms. The nondescript nature of the topography suggests that the sediments were deposited in an open trench in the ice surface rather than in subglacial or englacial tunnels. On the northeast side, the feature ends abruptly at an altitude as high or higher than that of the adjacent topography. This may indicate that some, if not all, of the glaciofluvial sediments were derived from drift on a higher ice surface. The nature of the gravel train and of the adjacent landforms indicates formation in a stagnant ice environment.

KAME COMPLEXES. — A large number of closely spaced mound-like hills, some elongate in plan, consisting mainly of glaciofluvial material are exposed in two areas between Medina and Woodworth. The hills rise from about 20 to more than 40 feet above intervening topographic lows and range in diameter from several tens to more than 200 feet. In this report these groups of landforms are referred to as kame complexes. One kame complex, located with its center in sec. 15, T. 141 N., R. 69 W., is about 4½ miles long and 1 mile wide. The second, located mainly within sec. 8, T. 141 N., R. 68 W., covers a little more than 1 square mile. Both kame complexes are bounded on one side by a pitted outwash plain and on another by hummocky stagnation moraine.

KETTLE CHAINS. — Though kettles are numerous throughout the west part of the county, three linear groups of kettles are especially conspicuous. The first group is located in a low area northwest of Woodworth with its center in sec. 24, T. 143 N., R. 69 W. To the north the kettle chain merges with ground moraine, but most of it is located in an area of hummocky stagnation moraine. The other two kettle chains trend east-west at the latitude of Medina (with centers in sec. 33, T. 140 N., R. 69 W., and in sec. 31, T. 140 N., R. 67 W.). Both are bounded by hummocky stagnation moraine and stagnation outwash. These kettle chains form linear topographically low troughs through which the Northern Pacific Railroad passes in the west-central part of the county.

CHARACTER OF THE DRIFT. — There is great variation in the character of the surficial drift associated with the landforms described above. Hummocky stagnation moraine is underlain mainly by till that consists of a matrix of clay and silt with lesser amounts of sand and granules. Pebbles and scattered cobbles and boulders are present also but make up a small proportion of the till. The till is similiar to other tills in the county and lacks any distinguishing physical characteristic.

Perched lacustrine plains are underlain mainly by stratified clay, silt and fine sand. In some instances, however, they contain till, coarse sand, and (or) gravel.

Stagnation outwash materials are stratified water-deposited sediments that range considerably in attitude, size of particles, and degree of sorting. The sediments range from well-sorted horizontal beds of sand and gravel to poorly sorted coarse gravel characterized by complex structures which have resulted from slumping.

THICKNESS OF THE DRIFT. — West of the Missouri Escarpment the total thickness of the glacial drift may range from less than 50 to more than 500 feet. However, the thickness of drift deposited by the last ice sheet that covered the area is not definitely known. Variations in the thickness of the drift are the result of differential deposition on an uneven bedrock surface. Thicknesses are greatest where topographic highs are located over bedrock valleys, and, conversely, the thickness is least where topographic lows are located in areas of bedrock highs (pls. 2 and 3). Subsurface data indicate that the average thickness of the drift in the west part of the county probably exceeds 200 feet and may exceed 300 feet. In Stutsman County the drift tends to be much thicker in the area known as the Coteau du Missouri than in the Drift Prairie, which is east of the Missouri Escarpment. Furthermore, the higher altitude of the Coteau du Missouri and the east-facing Missouri Escarpment is primarily the result of glacial deposition rather than an increase in the altitude of the bedrock.

INTERPRETATION. — After the deposition of the Streeter moraine the ice sheet was characterized by extensive stagnation. The width of the stagnant ice zone was at least 15 miles, possibly greater. The landforms located between the edge of the Missouri Escarpment and the proximal margin of the Streeter moraine were formed as the ice disintegrated in place. Glacial ice did not stagnate in Stutsman County in the area known as the Drift Prairie, which is east of the Missouri Escarpment. This is apparent because stagnation landforms are not found in the Drift Prairie in the county and because there is no evidence that the ice sheet, which would have covered all the Drift Prairie, readvanced significantly after construction of the Streeter moraine. The lack of glacial stagnation east of the Missouri Escarpment may be explained by the fact that the average altitude of the Drift Prairie is from 300 to 500 feet lower than the surface of the Coteau du Missouri. As a result of this difference in altitude, a thinning ice sheet could be characterized by extensive stagnation in the area of the Coteau du Missouri, but, because the ice would be at least 300 feet thicker, could continue to be active east of the Missouri Escarpment.

GROUND MORAINE ASSOCIATED WITH THE MISSOURI ESCARPMENT

The character of the east-facing Missouri Escarpment varies within the county. In some places the landscape consists of stagnation features, mainly the hummocky stagnation moraine described previously. In other areas ground moraine is the dominant landform associated with the escarpment.

In this report the ground moraine associated with the Missouri Escarpment is considered as a morphostratigraphic unit and is discussed separately from the landforms associated with the Coteau du Missouri and the Drift Prairie. The ground moraine is found in three areas: 1) An area about 25 square miles in the extreme northwest part of the county, 2) a larger area in the south-central part located east of Minneapolis Flats, and 3) a smaller area near the center of the county with its center in sec. 20, T. 141 N., R. 66W.

The ground moraine of the Missouri Escarpment has a surface that may slope as much as 75 feet per mile to the north or east. The ground moraine is found at a maximum altitude of about 1,800 feet above sea level near the crest of the escarpment and decreases to about 1,600 feet near the foot of the escarpment. The local relief, which may exceed 50 feet per square mile, is primarily the result of stream dissection on the sloping surface of the escarpment. Where the ground moraine is bounded by hummocky stagnation moraine of low altitude and high relief, the boundary is transitional rather than abrupt. However, in several places, hummocky stagnation moraine of high altitude and high relief borders on the ground moraine, and the contact between the two units is fairly sharp. The two areas of ground moraine in the central and south-central part of the county are bounded on the east by Minneapolis Flats and the Eldridge moraine. The ground moraine in the northwest part of the county extends north an unknown distance into Wells County.

LANDFORMS ASSOCIATED WITH THE GROUND MORAINE. — A low, winding ridge extends north from sec. 27, passes through sec. 22, and then turns east into sec. 23, T. 139 N., R. 66 W. The highest part of the ridge is 20 to 30 feet higher than the average altitude of the surrounding ground moraine. The ridge consists mainly of till with a thin veneer of sand and gravel at isolated places; the sand and gravel deposits are especially common on the southwest flank. The ridge is probably an ice-marginal depositional form and may mark a minor halt or readvance of the ice front.

Two tracts of glacial outwash are located in secs. 28, 32, and 33, T. 139 N., R. 66 W. Both deposits lack distinct topographic expression and probably represent local ice-marginal deposition by glacial melt water.

CHARACTER AND THICKNESS OF THE DRIFT. — The ground moraine is underlain mainly by till that is not noticeably different from other tills in the county. The thickness of the underlying drift is partly shown in test holes 1582, 1583, 1584, 1749, 1759, 1760, 1761, and 1762 (see cross sections C-C' and D-D'). The first three test holes are at 2-mile intervals at about the latitude of Interstate Highway 94 and the Northern Pacific Railroad; the logs indicate that the glacial drift is about 400 feet thick. The other test holes are located in the ground moraine in the south-central part of the county and indicate that the thickness of the glacial drift decreases from about 350 feet on the west to less than 100 feet on the east; thus, in this part of the county a well-defined bedrock escarpment is not present in the subsurface.

INTERPRETATION. — The ground moraine described above was uncovered as the ice margin retreated in an orderly manner from the Missouri Escarpment to the Drift Prairie. No evidence was observed to indicate that the ground moraine was formed by a significant readvance of the ice sheet some time after the formation of the stagnation landforms described previously. Thus, stagnant ice may have been present in the area known as the Coteau du Missouri when the active ice margin retreated from parts of the Missouri Escarpment. This interpretation is supported by the fact that the boundary between the ground moraine and some areas of hummocky stagnation moraine is transitional. Possibly the ground moraine was formed, at least in part, contemporaneously with stagnation landforms associated with the Coteau du Missouri.

LANDFORMS OF THE DRIFT PRAIRIE

In North Dakota the Drift Prairie consists of an undulating glaciated plain bounded on the west by the higher Missouri Plateau and on the east by the lower Red River valley, or Lake Agassiz plain (fig. 2). In Stutsman County the landforms consist mainly of ground moraine interrupted by end moraines and glacial melt-water channels that were formed in association with an active, rather than a stagnating, ice sheet. During the early stages of deglaciation the margin of a lobe of ice, restricted on the west by the Missouri Escarpment, retreated north from the James River lowland. The ice margin was characterized by several still-stands, representing either a halt during retreat or a readvance of the glacier, which resulted in the formation of several end moraines. Ground moraine, locally dissected by glacial melt-water channels, was formed in the intermorainal areas and is the most widespread landform in the east part of the county. In addition, outwash plains, eskers, kames, kame terraces and washboard moraines, among other landforms, are present in the Drift Prairie in Stutsman County.

Five morphostratigraphic units may be recognized within the Drift Prairie in the county. A morphostratigraphic unit may consist of an end moraine and the ground moraine on its proximal margin that was exposed as the ice margin retreated from a position marked by the end moraine. Other landforms that may be associated with a morphostratigraphic unit include outwash plains, washboard moraines, kames, eskers, and other features formed in association with the same phase of glacial activity. The five morphostratigraphic units are related to the following end moraines: (1) Millarton, (2) Eldridge, (3) Buchanan, (4) Grace City, and (5) Kensal (pl. 1).

MILLARTON MORAINE

The Millarton moraine, located at the foot of the Missouri Escarpment, trends north in Severn Township (T. 137 N., R. 64 W.) and terminates in sec. 26 in Lenton Township (T. 138 N., R. 65 W.). The moraine, averaging less than 1 mile in width, consists of a belt of low, rolling hills that rise from 30 to 50 feet above the ground moraine located on its proximal margin. The distal side of the moraine is well marked by Minneapolis Flats, which served as a melt-water channel and contains significant amounts of glacial outwash. The moraine may represent part of the "outer" member of the Antelope moraine recognized by Hard (1929, p. 28-29) in LaMoure County to the south. The moraine has not been traced southward in LaMoure County, however, and any definite correlation is tenuous. In view of this, the low belt of hills is herein named the Millarton moraine after a settlement located just east of it in sec. 24, T. 137 N., R. 65 W.

The Millarton moraine is the smallest and most poorly defined end moraine in the Drift Prairie in Stutsman County. It lacks a well-defined crest and consists of a linear group of hills and depressions aligned in a north-south direction. The maximum altitude of the moraine (NE¼ sec. 35, T. 138 N., R. 65 W.) is 1,590 to 1,600 feet above sea level, but its average altitude is about 1,550 to 1,560 feet above sea level. Both the ground moraine to the east and Minneapolis Flats to the west have an altitude of 1,500 to 1,520 feet above sea level, 30 to 60 feet lower than the average altitude of the moraine.

Lineations, apparent on aerial photographs and interpreted as washboard moraines, strike N30°W within the north-south trending moraine. Similiar linear patterns, with centers in secs. 18 and 19, T. 137 N., R. 64 W., are found in association with an area of ground moraine just west of the distal margin of the moraine. These lineations, also interpreted as washboard moraines, trend N66°W and are not conformable to the trend of the washboard moraines that are located within the Millarton moraine. This probably indicates that the ice margin was characterized by an interlobate situation or that there was a reorientation of the ice margin between the time the ground moraine and the end moraine were formed.

LANDFORMS ASSOCIATED WITH THE MILLARTON MORAINE

Three major landforms are associated with the Millarton moraine: 1) A melt-water channel located along the distal side of the moraine, 2) a melt-water channel trending northeast through the moraine to the distal side of the younger Eldridge moraine (with its center in sec. 32, T. 138 N., R. 64 W.), and 3) an extensive area of ground moraine located on the proximal side of the end moraine.

MINNEAPOLIS FLATS MELT-WATER CHANNELS. — This drainageway, located on the distal side of the Millarton moraine, consists of a broad, flat-bottomed, shallow valley that is underlain by glaciofluvial sediments. Minneapolis Flats served as an outlet for glacial melt water that drained from the southwest and west flank of the glacier as its margin receded to the north from the southeast part of the county. Some of the sand and gravel underlying the valley bottom probably was deposited from glacial melt water as the ice sheet formed the Millarton moraine. The exact relation between Minneapolis Flats and the end moraine, is not clear, however, because the former continued to be active as a melt-water channel after the ice margin had retreated some distance to the north. Probably

Minneapolis Flats served as an ice-marginal drainageway, at least in part, not only during and after the time that the Millarton moraine was formed, but also during and after the formation of the Eldridge moraine and possibly during the time the Buchanan moraine was formed.

MELT-WATER CHANNEL NEAR SYDNEY, — A second melt-water channel trends northeast from Minneapolis Flats to join Beaver Creek valley located along the distal margin of the Eldridge moraine. The altitude of the valley bottom is about 1,490 to 1,500 feet above sea level where it passes through the Millarton moraine and decreases to less than 1,480 feet above sea level where it joins Beaver Creek valley. The valley is not well defined topographically and sand and gravel are present in places on adjacent uplands (in secs. 29 and 32, T. 138 N., R. 64 W., pl. 1). The glaciofluvial material on the adjacent uplands lacks a distinct topographic expression and is mapped as undifferentiated outwash (pl. 1). In addition, two kames rise above the undifferentiated outwash in sec. 29, T. 138 N., R. 64 W.

This melt-water channel must have formed after the ice margin retreated from a position marked by the Millarton moraine to uncover a lower outlet for melt water than that offered by Minneapolis Flats. Melt water was diverted to the lower outlet and eventually drained to the James River valley by way of Beaver Creek valley. During the time the younger Eldridge moraine was formed, melt water drained to the James River valley by way of Beaver Creek valley rather than south to LaMoure County by way of Minneapolis Flats. Thus, the melt-water channel must have been formed after the construction of the Millarton moraine but before the formation of the Eldridge moraine. A similiar divergence of drainage from Minneapolis Flats to the James River valley is found in two other places in the county. As the ice margin retreated north from the east part of the county, apparently lower land was uncovered to the east, and the ice-marginal streams draining the west and southwest flank of the glacier reoriented themselves to the James River drainage system.

GROUND MORAINE ON THE PROXIMAL MARGIN OF THE MILLARTON MORAINE. — An extensive area of ground moraine is located on the proximal side of the Millarton moraine. The ground moraine is bounded on the west by the Millarton moraine and Minneapolis Flats and on the northeast by the Eldridge moraine and Beaver Creek valley. It extends south an unknown distance into LaMoure County. The east boundary of the ground moraine is not definitely known, however, because the Eldridge moraine does not extend all the way to the southeast corner of the county. A change in the character of the glacial drift is not apparent to the east although a different morphostratigraphic unit is probably present. Because of this, the east boundary of the ground moraine is arbitrarily defined as a line marked by the parts of Beaver Creek valley and the James River valley located southeast of the Eldridge moraine.

The altitude of the ground moraine averages from 1,480 to 1,500 feet above sea level, but isolated hills rise above this level. The topography is gently rolling and the local relief averages 20 feet per square mile. Steep slopes are common only along the flanks of several stream valleys that locally dissect the ground moraine. Linear trends, apparent on aerial photographs and representing the strike of washboard moraines, are common in the vicinity of Millarton. These reveal an arcuate pattern that is convex to the southwest. The trends of the washboard moraines are conformable to similiar linear trends in the Millarton moraine and indicate that the ground moraine was probably exposed as the ice margin retreated in an orderly fashion from the end moraine.

CHARACTER OF THE DRIFT. — The Millarton moraine and the ground moraine on its proximal margin consist mainly of till. The till appears similiar to other tills in the county, and field observations reveal no apparent distinguishing characteristic. Deposits in the melt-water channels consist largely of sand and fine gravel.

THICKNESS OF THE DRIFT. — The thickness of the glacial drift under-lying this morphostratigraphic unit varies from more than 200 feet to less than 50 feet.

The greatest thicknesses of drift tend to underlie the west part of the unit, and the drift tends to decrease in thickness to the northeast. Bedrock crops out at some places along the walls of Beaver Creek valley, which marks the northeast border of the unit.

INTERPRETATION. — The Millarton moraine and related landforms were developed in association with the southwest flank of a lobe of ice that was characterized by a margin that retreated north from the James River lowland. No evidence was found to indicate that the Millarton moraine was formed by a major readvance of the ice sheet. The moraine was probably formed during a slow-down, halt, or minor readvance of the ice margin, which may have been characterized by an interlobate situation. During the time the moraine was being formed, sand and gravel were probably deposited in Minneapolis Flats by melt water from the ice sheet.

After construction of the moraine, the ice margin retreated in a northeast direction and uncovered ground moraine and some washboard moraines. During the retreat a drainage outlet was formed that trended northeast from Minneapolis Flats, and melt water eventually followed this outlet to drain to the James River valley by way of Beaver Creek valley.

ELDRIDGE MORAINE

An end moraine, ranging from 1 to 5 miles in width but averaging 2 to 3 miles in width, extends north-northwest from the northwest corner of Montpellier Township (T. 137 N., R. 63 W.) for a distance of about 25 miles to a point where it is joined by the younger Buchanan moraine. Chamberlin (1883, p. 393-400), Todd (1896, p. 45-47, Willard (1909, p. 3) and Kresl (1956) describe morainal tracts in this general area, and with the exception of Chamberlin, refer to them as either the "Antelope" or "Third" moraine, or both. However, some lack of agreement exists regarding the areal extent and location of the morainal tracts, and none of the descriptions agree completely with the findings in this study. Furthermore, the genetic implications related to the terms "Antelope" and "Third" moraine, as described by Chamberlin and Todd, are no longer appropriate because concepts have changed regarding the age relationships of late Wisconsin moraines. To avoid confusion and misrepresentation, the writer proposed the name "Eldridge" be assigned to the moraine described below.[20]

The character of the Eldridge moraine is varied in nature. The distal margin of the feature is fairly well defined topographically as far north as Lippert Township (T. 139 N., R. 65 W.). North of the approximate latitude of Interstate Highway 94 for a distance of about 10 miles, however, the distal margin tends to be transitional with ground moraine and hummocky stagnation moraine. The distal margin is again fairly well defined from sec. 15, T. 141 N., R. 66 W., north to sec. 14, T. 142 N., R. 66 W. This part of the end moraine is bordered on the west by hummocky stagnation moraine and lacustrine sediments, both located at higher altitudes than the moraine itself.

In general, the proximal margin of the end moraine has a significant topographic expression. Near its southeast end, however, the moraine becomes less and less distinct and eventually all topographic expression disappears; also near its north end, where it is joined by the Buchanan moraine, the Eldridge moraine has little topographic expression. North of the point where the two moraines join, only one morainal ridge may be recognized. The proximal margin of the Eldridge moraine is generally about 20 to 50 feet higher than the adjacent landscape to the east, and this increase in altitude is present over a distance of a few hundred feet to a mile.

The Eldridge moraine lacks a distinct crest for much of its length. Instead a group of unconnected topographic highs are located within a belt of morainal topography that is characterized by numerous closed depressions and hillocks.

---

[20] Eldridge is a community located on the proximal side of the moraine in sec. 35, T. 140 N., R. 65 W.

The unconnected topographic highs may rise more than 50 feet above the surrounding morainal topography, which has local relief ranging from 20 to 40 feet per square mile. Examples of the higher hills in the morainal belt are found in secs. 16, 17, and 23, T. 138 N., R. 64 W.

Several kames are associated with this end moraine. The largest is in the SW¼ sec. 17, T. 138 N., R. 64 W., and other kames are located in sec. 34, T. 139 N., R. 64 W., secs. 23 and 26, T. 140 N., R. 66 W., and secs. 16 and 19, T. 140 N., R. 65 W. Numerous gravel-capped morainal hills are found also in secs. 1, 12, and 13, T. 141 N., R. 66 W.

An interlobate pattern is associated with the moraine in the vicinity of Kloze. Linear trends, apparent on aerial photographs and interpreted as washboard moraines, strike northwest just east and south of Kloze. Immediately to the northwest of the community, however, similiar linear patterns strike east and northeast. In the vicinity of Kloze, morainal topography is well developed and an appendage of the moraine extends east through sec. 35 into sec. 36, T. 136 N., R. 64 W. The rugged topography in this part of the moraine may be, at least in part, the result of an interlobate development.

Two areas in the moraine are characterized by subdued morainal topography, where in contrast to the landforms generally associated with the end moraine, the local relief may be less than 20 feet per square mile. Because of their location these areas (with centers in sec. 28, T. 139 N., R. 65 W. and sec. 33, T. 140 N., R. 65 W.) are known to be genetically related to the moraine and are mapped as subdued end moraine (pl. 1).

LANDFORMS ASSOCIATED WITH THE ELDRIDGE MORAINE

Major landforms associated with the Eldridge moraine include: 1) Melt-water channels and a perched lacustrine plain in the distal margin of the feature; 2) ground moraine, various outwash forms, and a lacustrine plain on the proximal side of the end moraine; and 3) a melt-water channel that bisects the moraine. The Eldridge moraine and these genetically related landforms comprise a morphostratigraphic unit.

MINNEAPOLIS FLATS AND BEAVER CREEK MELT-WATER CHANNELS. — Minneapolis Flats is a former glacial melt-water channel that trends south from sec. 5, T. 140 N., R. 65 W. and passes through the end moraine in Eldridge Township (T. 140 N., R. 65 W.). Farther south the channel is located on the distal side of the moraine in Lippert Township (T. 139 N., R. 65 W.). Minneapolis Flats, as has been previously stated, served as an outlet for melt water during the formation of the Millarton moraine. The part of Minneapolis Flats north of sec. 4, T. 138 N., R. 65 W. probably continued to serve as a drainageway for melt water during and after the time the ice formed the Eldridge moraine. South of sec. 4, however, the melt water was probably diverted from Minneapolis Flats to a lower outlet, Beaver Creek valley, located along the distal margin of the Eldridge moraine. Glaciofluvial material was deposited in both valleys during the time that they served as melt-water channels.

A small outwash plain, located in sec. 21, 22, 27, and 28, T. 138 N., R. 63 W., extends southwest from the distal side of the Eldridge moraine. Beaver Creek valley is intrenched into this outwash plain and divides it into north and south sections. Probably the outwash was deposited from melt water when the ice sheet was forming the Eldridge moraine. If this interpretation is correct, significant downcutting occurred in Beaver Creek valley after the outwash plain was formed.

PERCHED LACUSTRINE PLAIN WEST OF BUCHANAN. — A perched lacustrine plain is located along the distal side of the Eldridge moraine 9 miles west of Buchanan in secs. 2, 3, 10, and 11, T. 141 N., R. 66 W. (pl. 1). It is bounded on the west by hummocky stagnation moraine. Numerous exposures along the section-line roads reveal that clay and silt are the most common sediments of the feature. Several exposures, the most notable along a stream bank in the NW¼ sec. 11, T. 141 N.,

R. 66 W., reveal till underlying horizontally bedded clay and silt. The altitude of the lacustrine sediments ranges from 1,700 to 1,800 feet above sea level. The highest part of the Eldridge moraine to the east is about 1,700 feet above sea level. The east boundary of the perched lacustrine plain is transitional with the morainal topography of the Eldridge moraine. In no place was till observed overlying the lacustrine sediments; perhaps, therefore, the perched lacustrine plain existed along the margin of the ice sheet at the time that the end moraine was formed. This interpretation, if correct, may also indicate that stagnant glacial ice still existed in the Coteau du Missouri when this part of the Eldridge moraine was formed because closed depressions within hummocky stagnation moraine to the west are found at lower altitudes than the sediments of the perched lacustrine plain. The closed depressions are not filled with clay and silt, which indicates that ice must have existed in the area and restricted the extent of the deposits of the lacustrine plain.

GROUND MORAINE ON THE PROXIMAL MARGIN OF THE ELDRIDGE MORAINE. — Ground moraine is the most extensive landform on the proximal side of the Eldridge moraine. The ground moraine is bounded on the north by the Buchanan moraine and on the east, in part, by drift associated with the Kensal moraine. In the southeast part of the county the ground moraine probably extends into Barnes and possibly LaMoure Counties (see discussion of Ground moraine on the proximal margin of the Millarton moraine), but the boundaries are not definitely known.

Generally the altitude of the ground moraine ranges from 1,480 to 1,530 feet above sea level. The average altitude is about 1,500 feet above sea level, and the local relief is usually less than 25 feet per square mile. Shallow closed depressions are common but seldom exceed 10 feet in depth. Numerous washboard moraines and small kames are located in some areas of the ground moraine. These are described in detail below.

WASHBOARD MORAINES ASSOCIATED WITH THE GROUND MORAINE ON THE PROXIMAL MARGIN OF THE ELDRIDGE MORAINE. — Though washboard moraines are found in many areas in the east part of the county, they are especially numerous immediately east, south, and west of Jamestown. The strike of their axes reveals an interlobate pattern in secs. 24 and 25, T. 139 N., R. 64 W., just northeast of Kloze. Between Kloze and Eldridge the strike of the washboard moraines forms an arcuate pattern convex to the southwest. Between Kloze and the James River valley to the east, the strike of the washboard moraines shows a lobate pattern convex to the south. Several miles east of the James River valley the washboard moraines are sharply truncated by deposits of younger glacial drift associated with the Kensal moraine. The long axes of all the washboard moraines are roughly conformable to similiar lineations associated with the Eldridge moraine. The number of washboard moraines decreases to the north and they disappear completely immediately south of the Buchanan moraine.

In the vicinity of Eldridge the washboard moraines are numerous and exceptionally well developed (fig. 5). In this area the topography, which distinctly reflects the linear trends of the features, consists of low hills and intervening elongate shallow depressions parallel to the strike of the washboard moraines. This is also true to a much lesser degree in secs. 16, 17, 20 and 21, T. 139 N., R. 62 W. Kresl (1956) mapped the elongate low hills as recessional moraines in the Eldridge area.

In the south half of Homer Township (T. 139 N., R. 63 W.) the washboard moraines are also numerous but are not as distinct topographically. As a result the low hills and shallow depressions do not noticeably reflect the strike of the washboard moraines. In the vicinity of the Jamestown Airport (sec. 19, T. 140 N., R. 63 W.) washboard moraines are absent, and the local relief is less than that of the areas described above.

In conclusion, washboard moraines probably increase the local relief where they are present in association with ground moraine. Where they are well developed and numerous, the topography may directly reflect their trend and arrangement. In areas where they are poorly dveloped, there may be low hills that possibly mark the areal extent of a group of the washboard moraines but do not necessarily reflect their trend.

ESKERS AND KAMES ASSOCIATED WITH THE GROUND MORAINE ON THE PROXIMAL MARGIN OF THE ELDRIDGE MORINE. — A large number of kames and one esker are located in the part of the ground moraine south of the latitude of Jamestown (pl. 1). The kames rise from 5 to 25 feet above the ground moraine and most are associated with topographic highs that consist of till. The glaciofluvial sediments in the kames range from a few feet to more than 20 feet in thickness. Generally the slopes of the kames are in sharp contrast to the slopes of the surrounding ground moraine.

A well-defined esker trends south through secs. 23 and 25, T. 139 N., R. 64 W. (pl. 1). The crest of the esker is 15 to 20 feet higher than the adjacent ground moraine. The esker is not continuous but consists of six elongate ridges ranging from 500 to 2,000 feet in length. A topographic low parallels the esker in sec. 23 but is absent in sec. 25.

A notable relation exists between the landforms described above and the washboard moraines. The esker is in the area where washboard moraines reflect an interlobate pattern. In many places the kames are along the strike of the washboard moraines. Elson (1957b, p. 1721) states that kames are commonly related to washboard moraines; the presence of the kames suggests that active ice was in contact with stagnant ice at the margin of the glacier. He further states that eskers are likely to be found where washboard moraines exhibit an interlobate pattern. Elson's concepts regarding the possible relation between washboard morains and kames and eskers are substantiated in this area.

The preservation and interrelation of the washboard moraines, the small kames, and the esker suggest that all of them formed in association with a retreating ice margin rather than with an advancing ice margin or a glacier that was characterized by extensive stagnation. An advancing ice sheet would probably have obliterated these features, and a glacier characterized by extensive stagnation could not have produced the washboard moraines.

Numerous kames and one esker, the latter in sec. 32, T. 141 N., R. 65 W., are in the part of the ground moraine north of the latitude of Jamestown. The largest kames are in a group in secs. 14, 23, and 26, T. 141 N., R. 63 W. and are not associated with this morphostratigraphic unit. These kames were formed at the edge of an ice sheet that readvanced to form the Kensal moraine after the ground moraine had been formed (see discussion of ICE-MARGINAL KAMES ASSOCIATED WITH THE KENSAL MORAINE).

JAMES-PIPESTEM MELTWATER CHANNELS. — The ground moraine in the proximal margin of the Eldrige moraine has been partly dissected by several glacial melt-water channels. The largest of these, now known as the James River valley and Pipestem Creek valley, are characterized by relatively wide flat bottoms and steep valley walls. Large amounts of glaciofluvial material are found in terraces along the valley walls and beneath the valley bottoms in Pipestem Creek valley and the part of the James River valley located south of Jamestown. Pipestem Creek valley ranges generally from a quarter of a mile to half a mile in width, and the valley bottom is 50 to 75 feet below the average altitude of the ground moraine. The James River valley ranges generally from half a mile to 1¼ miles wide and the valley bottom is from 80 to 120 feet lower than the adjacent ground moraine. Both valleys presently contain underfit streams. The size of the valleys and the large amount of glaciofluvial sediments are primarily the result of erosion and deposition by glacial melt water.

These valleys are not known to have existed previous to the time the area was last glaciated. As the ice margin retreated north from the James River lowland, however, large amounts of glacial melt water must have drained south by way of the James River valley. This major drainageway was joined by several tributary melt-water channels including Bone Hill Creek valley to the south in LaMoure County, and Beaver Creek valley in the south part of Stutsman County. Continued retreat of the ice margin to the north resulted in the northward lengthening of the drainage system. At the time the ice margin retreated north from the Eldridge moraine to the Buchanan moraine, the part of the James River valley north of Jamestown and the lower portion of Sevenmile Coulee probably did not exist or, if they did exist, they bore little resemblance to the present valleys. Both drainageways probably were formed largely as a result of later glacial events. At the time of the northward retreat of the ice margin, most likely only one major melt-water channel existed in the area — Pipestem Creek valley and its southward continuation, the part of the James River valley located south of Jamestown (see Drainage History).

SEVENMILE COULEE MELT-WATER CHANNEL. — Sevenmile Coulee, located about 2 miles west of Spiritwood, also acted as a glacial melt-water channel. The valley is flat bottomed, varies from about a quarter of a mile to 1 mile in width, and is from 50 to 80 feet deep. Striking variations in the character of the coulee are apparent and it may be divided into three sections: 1) The upper section, which extends from sec. 1 to sec. 25 in Fried Township (T. 141 N., R. 63 W.) and is narrow and irregular; 2) the middle section, which extends south from sec. 30 in Fried Township (T. 141 N., R. 63 W.) to sec. 19 in Spiritwood Township (T. 140 N., R. 62 W.) and averages about a quarter of a mile in width; and 3) the lower section, which exceeds half a mile in width and trends south-southwest to join the James River valley (pl. 1). Glaciofluvial sediments and terraces are present in all sections of the coulee.

The middle section of Sevenmile Coulee probably served as an outlet for glacial melt water as the ice margin retreated north from the Eldridge moraine. Later glacial events, however, resulted in major changes in the character of the coulee. These changes, which account for both the upper and the lower sections of Sevenmile Coulee, are described in the discussion of the drainage history of the area.

LACUSTRINE PLAIN AND MELT-WATER CHANNEL NEAR KLOZE. — The proximal slope of the Eldridge moraine is separated from the ground moraine to the northeast by a small lacustrine plain and a glacial melt-water channel in Sydney (T. 138N., R. 64 W.) and Corwin (T. 138 N., R. 63 W.) Townships (pl. 1). Significant amounts of glaciofluvial sediments are associated with the melt-water channel. The sand and gravel deposits are generally poorly sorted and coarse to the south and grade into well-sorted, finer material to the north. The thickness of the sand and gravel is not known.

In sec. 2, T. 138 N., R. 64 W., the glaciofluvial materials grade into lacustrine sediments to the north. At the periphery of the lacustrine plain, the sediments are underlain by till. The approximate altitude of the lacustrine plain is 1,480 feet above sea level and the local relief is generally less than 5 feet.

The landforms and sediments described above record the existence of a small glacial lake and melt-water channel that formed as the ice retreated from the Eldridge moraine. The melt-water channel probably served as a drainageway for water from the ice and as an outlet to the temporary lake.

STREAMAN COULEE MELT-WATER CHANNEL. — Streaman Coulee, which joins the James River valley in sec. 30, T. 138 N., R. 62 W., was also formed as a melt-water channel. Near the James River valley the coulee averages less than a quarter of a mile in width and is intrenched more than 70 feet in the adjacent ground moraine. The valley becomes less well defined upstream and eventually merges with an extensive tract of outwash in secs. 14, 15, 22 and 23, T. 139 N., R. 62 W. The Coulee may have been active as a melt-water channel when the ice retreated north from the James River lowland or it may have been formed as a result of a later readvance of the ice sheet that deposited the Kensal moraine.

OUTWASH PLAIN IN SOUTHERN HIDDEN TOWNSHIP. — A tract of glacial outwash covers part of southern Hidden Township (T. 141 N., R. 65 W.). The outwash is bounded on the north by the Buchanan moraine and grades into Minneapolis Flats on the south. On the west and southeast the outwash is bounded by ground moraine, but the contact is transitional rather than sharp. The altitude of the outwash decreases from about 1,560 feet above sea level on the west and northwest to about 1,525 feet above sea level on the east and southeast. In addition, closed depressions in the form of pits, or kettles, and dissection by Pipestem Creek and one of its tributaries account for additional relief. The feature is interpreted as an outwash plain that probably formed, for the most part, from local deposition by glacial melt water along the margin of the ice sheet as it retreated to the north. This interpretation would account for the variations in altitude, the presence of the closed depressions, and the lack of a constant slope away from the distal margin of the Buchanan moraine.

Character Of The Drift. — The Eldridge moraine and the ground moraine on its proximal margin consist mainly of till. The till appears similiar to other tills in the county and no significant variation in its physical characteristics was observed that would permit definite differentiation. Horizontal and cross-bedded sand and gravel deposits are present in the glacial melt-water channels. Local deposits of glaciofluvial sediments, which vary greatly in character, are found in the kames and eskers.

Thickness Of The Drift. — The thickness of the glacial drift underlying this morphostratigraphic unit ranges from less than 10 feet to more than 500 feet. The variation in thickness is primarily the result of relief on the bedrock surface rather than differences in altitude of the present-day topography. The thickness of the drift generally tends to increase toward the east and to be thickest along the east boundary of the county. Local variations in this overall pattern are probably the result of bedrock valleys that have been filled with glacial drift. The amount of glacial drift deposited by the last glacial advance and retreat in this part of the county is not definitely known.

Interpretation. — The Eldridge moraine and associated landforms were formed at the edge of an interlobate ice margin that was receding to the north. The moraine was probably formed on the southwest flank of the lobe of ice that had previously deposited the Millarton moraine. Thus, the moraine may be a recessional feature and probably does not mark the terminal position of a significant readvance of the ice sheet. Evidence for this interpretation is as follows: 1) Linear patterns in the end moraine are conformable to the trends of washboard moraines on both the proximal and distal sides, 2) no significant variation exists between the character of the glacial drift associated with the moraine and that of the drift previously deposited on the proximal margin, and 3) no evidence that the moraine was formed by a significant readvance of the ice sheet was found.

During the formation of the Eldridge moraine, Minneapolis Flats, Beaver Creek valley, and the James River valley served in part, at least, as melt-water channels. Retreat of the ice margin in an orderly manner resulted in the formation of a melt-water channel and a temporary lake along the proximal margin of the moraine near Kloze. Continued retreat of the ice margin uncovered an extensive tract of ground moraine characterized in places by washboard moraines, which are recessional features. As the ice margin retreated to the north, the part of the James River valley south of Jamestown and Pipestem Creek valley served as the major drainageways for melt water while Beaver Creek valley and Minneapolis Flats eventually ceased to be important as melt-water channels. The middle portion of Sevenmile Coulee may also have served as an outlet for melt water as the ice receded. Finally, when the ice margin was at the position marked by the Buchanan moraine, an outwash plain was formed in southern Hidden Township (T. 141 N., R. 65 W.).

BUCHANAN MORAINE

A moraine, herein named after the settlement of Buchanan, which is located on its proximal margin, extends in an arcuate manner from the approximate location of Blue Lake, located in Ashland Township (T. 142 N., R. 63 W.), to sec. 6, T.

141 N., R. 65 W. On the west it merges with the Eldridge moraine, and on the east it is truncated by the younger Kensal moraine. The moraine is about 15 miles long and ranges generally from 1 to 5 miles in width (pl. 1).

In general, the distal margin of the Buchanan moraine is well defined topographically. This is especially true in Fried Township (T. 141 N., R. 63 W.) (fig. 19). The proximal margin, however, is not distinct, but is transitional with ground moraine in most places. The east part of the moraine is characterized by a prominent southwest-trending crest that is located closest to the distal margin. A continuous crest is lacking in the central and west parts of the moraine, although isolated hills rising above morainal topography are common. Local relief is greatest in the east part of the moraine and may exceed 100 feet per square mile, but the average relief per square mile in this area is about 50 to 75 feet. In the central and west parts of the moraine, local relief averages 30 to 40 feet per square mile in areas where melt-water channels are absent. Lineations, parallel to the strike of the moraine, are apparent on aerial photographs of the east part of the moraine but do not show up in the west part.

FIGURE 19

Distal slope of the Buchanan moraine as viewed looking north from the NW¼ sec. 3, T. 141 N., R. 63 W.

Several melt-water channels trend south through the moraine. The major ones are the James River valley and Pipestem Creek valley. Others include a small valley trending southeast through Buchanan Township (T. 141 N., R. 64 W.) and a complex system of valleys located just east of the James River valley. All the melt-water channels serve to increase the local relief markedly.

LANDFORMS ASSOCIATED WITH THE BUCHANAN MORAINE

Major landforms associated with the Buchanan moraine include: 1) An extensive area of ground moraine on the proximal margin of the feature, 2) an outwash plain located on the proximal margin of the moraine, and 3) several melt-water channels that trend south through the end moraine and the ground moraine located on its proximal margin (pl. 1). The Buchanan moraine and these related landforms constitute a morphostratigraphic unit.

GROUND MORAINE ON THE PROXIMAL SIDE OF THE BUCHANAN MORAINE. — An extensive tract of ground moraine is located north of the Buchanan moraine. The ground moraine is bounded on the west by landforms associated with the Missouri Escarpment, on the north by the younger Grace City moraine, and on the east by subdued morainal topography formed by the ice sheet that deposited the Kensal moraine.

East of Pipestem Creek valley the ground moraine has an average altitude of about 1,550 feet above sea level. The local relief averages about 20 feet per square mile and seldom exceeds 30 feet per square mile. West of Pipestem Creek valley the ground moraine increases in altitude from about 1,550 to 1,625 feet above sea level along the foot of the Missouri Escarpment. The local relief is more rugged than that east of Pipestem Creek valley because of the effect of the Missouri Escarpment and because of greater amounts of stream dissection on the east-sloping surface.

Local relief is greatest in the immediate vicinity of the major melt-water channels located in the ground moraine. In these areas erosion by running water has dissected the ground moraine, making the topography rugged. The greatest amount of dissection exists along the west side of Pipestem Creek valley.

Kames have not been found to occur in the ground moraine, but an esker is located in secs. 4 and 9, T. 142 N., R. 65 W. The esker, which is not conspicuous, trends north-south and seldom exceeds 10 feet in height.

OUTWASH PLAIN NORTH OF BUCHANAN. — An outwash plain covers less than 10 square miles northeast of Buchanan. It is bounded on the south by the Buchanan moraine and on all other sides by ground moraine. In many places, however, the boundary between the outwash plain and the adjacent ground moraine or end moraine is difficult to locate because it is transitional in nature. The average altitude of the outwash plain is 1,530 to 1,540 feet above sea level, but numerous low hills rise above this surface. Local relief averages from 10 to 20 feet per square mile. The glaciofluvial sediments may have been deposited on a gently rolling till surface; at places till is observed beneath the deposit of outwash. This is clearly shown in a road cut along the west side of the SW¼ sec. 28, T. 142 N., R. 64 W., where a sharp contact separates several feet of water-deposited sand and gravel from an underlying oxidized calcareous till. Some of the local relief associated with the outwash plain may be the result of till knobs that rise above and are surrounded by glacial outwash. The glaciofluvial sediments were probably deposited outward from the ice margin that retreated north from the Buchanan moraine.

PIPESTEM AND JAMES MELT-WATER CHANNELS. — Two major melt-water channels, Pipestem Creek valley and the James River valley, trend south through the Buchanan moraine and the ground moraine described above. Pipestem Creek valley ranges generally from a quarter of a mile to half a mile in width where it passes through the moraine. To the north, however, the valley widens until, near the distal margin of the Grace City moraine, it may exceed 1 mile in width. The valley contains large amounts of glacial outwash, some of which is in terraces along the valley walls. The James River valley averages about a third of a mile in width. It is, in part, intrenched in bedrock. Glaciofluvial materials in the valley are not as extensive as those in Pipestem Creek valley, and only one terrace is north of the latitude of Jamestown. Both melt-water channels are joined by numerous smaller tributary valleys, some of which served as local melt-water channels.

Pipestem Creek valley, served as a melt-water channel while the ice retreated north from the Eldridge moraine. The valley continued to act as a drainageway as the margin of the ice retreated north from the Buchanan moraine. The part of the James River valley located north of Jamestown, however, probably was developed largely as a result of later glacial events, and, if a valley did exist at the time the ice margin retreated north from the Buchanan moraine, it probably bore little resemblance to the present valley and was not as important a melt-water channel as Pipestem Creek valley (see Drainage History).

CHARACTER OF THE DRIFT. — The Buchanan moraine and the ground moraine on its proximal margin are underlain mainly by till. No characteristics were observed that would serve to distinguish this till from other surficial tills in the county. The sediments comprising the outwash plain northeast of Buchanan consist primarily of stratified sand and fine gravel interbedded with some clay and silt. Cobbles and boulders are rare in these deposits. The glaciofluvial sediments in the melt-water channels also consist mainly of sand and gravel although cobbles and boulders are not uncommon. Shale is more abundant in the outwash in the James River valley than in that of the Pipestem Creek valley.

THICKNESS OF THE DRIFT. — The average thickness of the glacial drift in this morphostratigraphic unit is probably less than 100 feet. In west-central Jim River Valley Township (T. 142 N., R. 65 W.) the average thickness of the drift is probably less than 50 feet. In certain areas where valleys cut the bedrock surface, the glacial drift may exceed 100, or possibly even 200, feet in thickness. This is probably true in central Plainview (T. 142 N., R. 65 W.) and Pingree (T. 143 N., R. 65 W.) Townships and in southeast Pipestem Valley Township (T. 143 N., R. 65 W.). The amount of glacial drift deposited prior to the last glaciation of the area is not definitely known.

INTERPRETATION. — The landforms of this morphostratigraphic unit were formed by a lobe of ice characterized by a margin that retreated north in an orderly manner from the Buchanan moraine. The Buchanan moraine probably does not mark the terminal position of a significant readvance of the ice sheet. Thus, the moraine is probably a recessional feature formed at the margin of a shrinking ice sheet that had previously formed the Eldridge and Millarton moraines. Evidence for this interpretation includes the following: 1) The pattern of washboard moraines on the ground moraine located south of the Buchanan moraine are roughly conformable to the trend of the moraine; 2) the Buchanan moraine merges with the Eldridge moraine on the west in a transitional manner and cross-cutting relationships between the two moraines are not known to exist; and 3) a significant difference between the drift of this morphostratigraphic unit and the drift previously deposited on the distal side of the Buchanan moraine is lacking.

After construction of the Buchanan moraine, the ice margin retreated to the north, uncovering an extensive area of ground moraine and leaving an outwash plain northeast of Buchanan. During the retreat Pipestem Creek valley served as the major melt-water channel in the area.

GRACE CITY MORAINE

An end moraine, referred to by Lemke and Colton (1958, p. 50, fig. 5) as the Grace City moraine, extends in an arcuate manner from Foster County through sec. 1, T. 144 N., R. 65 W., passes south of Edmunds, and continues west to sec. 25, T. 144 N., R. 67 W. in the north-central part of the county (pl. 1). The part of the moraine in Stutsman County is about 18 miles in length and ranges from less than 1 mile to about 3 miles in width.

The Grace City moraine in Stutsman County may best be described as a curvilinear group of low, gently rolling hills that rise above adjacent areas of ground moraine. Although the moraine has a linear ridge of glacial drift that was probably deposited primarily at the margin of an ice sheet, it does not exhibit well-developed morainal topography. The distal boundary is well defined in Edmunds Township (T. 143 N., R. 65 W.) at an altitude of about 1,550 feet above sea level. To the east and west of Edmunds Township, however, where the moraine is bounded by the James River valley and the Missouri Escarpment respectively, the distal edge is somewhat obscure. The proximal margin is everywhere transitional with ground moraine. A fairly well-defined crest, 50 to 75 feet higher than the adjacent ground moraine, is present in secs. 8, 9, 10 and 11, T. 143 N., R. 65 W. Elsewhere the height of the crest is generally less than 60 feet and is not nearly as conspicuous. Local relief is greatest in the central and extreme west parts of the moraine, but rugged depositional morainal topography is absent throughout much of the feature. Kettles are present, although they tend to be shallow and poorly defined, and boulders, sometimes common in end moraines, are rare. In the parts of the moraine that parallel the James River valley to the north in Foster County, however, morainal topography is well developed.

Several kames are located in the part of the moraine that is immediately west of the James River valley in Stutsman County and in Foster County to the north. Irregular tracts of outwash, lacking distinct topographic expression, are also common in this area. The kames and the outwash may be the result of concentrations of large amounts of melt-water in an interlobate area bounded on the west by ice that deposited the Grace City moraine and on the east by ice that formed the Kensal moraine. The relation between the Grace City moraine and the Kensal moraine is discussed later in this report.

LANDFORMS ASSOCIATED WITH THE GRACE CITY MORAINE

Major landforms associated with the Grace City moraine include: 1) Outwash forms on the distal margin of the moraine in Pipestem Valley Township (T. 143 N., R. 66 W.); 2) a large tract of ground moraine that extends into Foster County; and 3) two large melt-water channels, now known as Pipestem Creek valley and the James River valley. The Grace City moraine and these associated landforms constitute a morphostratigraphic unit (pl. 1).

Outwash forms in Pipestem Valley Township. — A linear tract of glacial outwash located on the distal side of the Grace City moraine extends southeast from sec. 36, T. 144 N., R. 67 W. to sec. 25, T. 143 N., R. 66 W., where it joins outwash associated with Pipestem Creek valley. The sediments consist of sand and some coarse gravel; they are poorly sorted in the northwest part of the deposit. The topography of the outwash deposits suggests that they were laid down partly in an outwash plain and partly in a glacial melt-water channel. In the southeast corner of Glacier Township (T. 144N., R. 67 W.) the outwash is at an altitude of about 1,720 to 1,730 feet above sea level. The surface altitude of the sand and gravel decreases to the southeast until, at the junction with Pipestem Creek valley, it is about 1,525 to 1,550 feet above sea level. At some places in secs. 7, 8, 17 and 18, T. 143 N., R. 66 W., the outwash is on both the distal side of the Grace City moraine sloping to the southwest and on the lower part of the Missouri Escarpment sloping to the east. This may indicate that the glaciofluvial sediments were deposited by melt-water draining east from the Coteau du Missouri and southwest from the glacier that constucted the Grace City moraine. It is not known that these glaciofluvial sediments were deposited contemporaneously.

In secs. 21, 22, and 26, T. 143 N., R. 66 W., the linear outwash plain ranges considerably in width and consists of a relatively flat surface interrupted by a shallow, meandering valley, which contains an intermittent stream. The shallow stream valley was probably formed by erosion after the glacier retreated from the Grace City moraine.

Ground moraine in the vicinity of Edmunds. — Ground moraine, interrupted by one major melt-water channel, extends north from the proximal margin of the Grace City moraine into Foster County. East of the longitude of Edmunds the ground moraine has an average altitude of about 1,540 feet above sea level and the local relief is 10 to 20 feet per square mile where stream dissection is absent. Some of the local relief results from shallow, closed depressions that are especially numerous in the north half of Edmunds Township (T. 144 N., R. 65 W.). Linear trends, apparent on aerial photographs and interpreted as washboard moraines, strike northeast in secs. 4, 5, 6, 8, and 9, T. 144 N., R. 65 W., and are conformable to the part of the Grace City moraine that parallels the James River valley. This indicates that the ice margin receded to the northwest across this part of the ground moraine.

West from the longitude of Edmunds the average altitude of the ground moraine gradually increases and exceeds 1,600 feet above sea level before it merges with either the Grace City moraine or with hummocky stagnation moraine. In addition, the local relief tends to increase to the west and commonly exceeds 30 feet per square mile immediately west of Pipestem Creek valley. Although there is a notable variation in the topography to the west, boundaries between different types of major landforms are difficult to establish, because the change is transitional and the Grace City moraine cannot be traced north of sec. 25, T. 144 N., R. 67. W.

Two small kames are located in secs. 9 and 16, T. 144 N., R. 66 W., and small, irregular deposits of outwash are common in many places in the ground moraine. Lacustrine sediments are present locally in many of the shallow, closed depressions. The most extensive deposits of lacustrine sediments has its center in sec. 33, T. 144 N., R. 65 W., two miles east of Edmunds.

PIPESTEM CREEK MELT-WATER CHANNEL. — This valley, which served as a glacial melt-water channel, trends southeast across the west part of the ground moraine described above, passes through the Grace City moraine southwest of Edmunds, and continues south-southeast toward the Buchanan moraine. North of the Grace City moraine the valley ranges generally from about half a mile to three-quarters of a mile in width and becomes less distinct topographically to the northwest. The valley narrows abruptly to about a third of a mile in width where it passes through the Grace City moraine. In this area the valley is well defined and Pipestem Creek is about 75 feet lower in altitude than the high parts of the moraine. South of the moraine the valley widens to about 1 mile, but it gradually becomes narrower again farther to the south.

Large amounts of sand and gravel are preesnt in the valley and are especially abundant both north and south of the Grace City moraine. North of the moraine the glaciofluvial sediments underlie the broad, flat valley bottom and well-defined terraces of glaciofluvial material are not preesnt. South of the moraine sand and gravel are found: 1) beneath the broad, flat valley floor, 2) in terraces along both valley walls, and 3) in association with an outwash plain that is located on the east side of Pipestem Creek valley and that extends south from the distal side of the Grace City moraine.

Pipestem Creek valley served as a melt-water channel after the ice margin retreated from the Eldridge moraine and during and after the construction of the Buchanan moraine. Apparently glacial melt water continued to drain south by way of this channel during the time that the Grace City moraine was formed, because landforms consisting of sand and gravel extend outward from the distal side of the moraine and are associated with the melt-water channel. As the ice margin retreated north from the moraine, the channel probably increased its length northward by headward erosion and continued to serve as an outlet for melt water.

JAMES RIVER VALLEY MELT-WATER CHANNEL. — This flat-bottomed, steep-walled valley enters the county in sec. 6, T. 144 N., R. 64 W., and trends south along the distal margin of the Grace City moraine for a distance of about 8 miles. The valley ranges from half a mile to three-quarters of a mile in width and presently contains large man-made bodies of water, Arrowwood Lake and Jim Lake, with surface altitudes of 1,435 to 1,440 feet above sea level. The bottom of the valley is more than 60 feet lower than the adjacent uplands, and the terraces are located at some places along the valley walls. Large amounts of sand and gravel are associated with a terrace that has its center in secs. 18 and 20, T. 143 N., R. 64 W. The amount of glaciofluvial material beneath the valley floor is not known.

It is not definitely known that the James River valley served as a major outlet for glacial melt water during the time that the Grace City moraine was formed. If the Grace City moraine was formed contemporaneously with or some time after the formation of the Kensal moraine to the east, the valley undoubtedly served as an outlet for melt water from ice that constructed the Grace City moraine. If, however, the Grace City moraine pre-dates the Kensal moraine and the latter was formed by a later readvance of the ice sheet, melt water may have drained southeast from the Grace City moraine by way of one or more channels which were later obstructed by or filled with drift from the ice that formed the Kensal moraine. This problem is discussed in greater detail later in this report.

CHARACTER OF THE DRIFT. — The Grace City moraine and the ground moraine on its proximal margin consist mainly of till. Size analyses of samples suggest that the till is similiar to other tills in the county. It should be noted, however, that masses of silt and clay are unusually abundunt in the till in many exposures that were examined. It is not known that this is a distinctive characteristic of all till associated with the end moraine and ground moraine outside Stutsman County. Glaciofluvial sediments associated with melt-water channels and outwash plains consist mainly of horizontally bedded and cross-bedded sand and fine gravel.

THICKNESS OF THE DRIFT. — In the west part of this morphostratigraphic unit, in Glacier Township (T. 144 N., R. 67 W.), southwest Walters Township (T. 144 N., R. 66 W.) and northwest Pipestem Valley Township (T. 143 N., R. 66 W.), the thickness of the glacial drift probably averages less than 150 feet. In east-central Pipestem Valley Township (T. 143 N., R. 66 W.) and north-central Pingree Township (T. 143 N., R. 65 W.) the average thickness may exceed this figure, if this was the location of the ancestral Cannonball River (pl. 2, arrow B). The thickness of the drift north of Edmunds is questionable but available data indicate that it is probably more than 50 feet thick at most places. The amount of drift deposited by the ice sheet that formed the Grace City moraine and its related landforms is not definitely known.

INTERPRETATION. — The Grace City moraine may be associated with an ice margin that retreated from the Buchanan moraine, or it may mark the terminal position of a significant readvance of the ice sheet after its margin had retreated an unknown distance to the north. The trend of the moraine is roughly conformable to that of the Buchanan moraine to the south, which suggests that the Grace City moraine may be a recessional feature. On the east, however, the moraine is bounded by drift deposited by ice that formed the Kensal moraine. The Kensal moraine is known to have been constructed by a readvance of the ice, but cross-cutting relations between the two moraines do not exist in the county. Lemke and Colton (1958, p. 50) suggest that the Grace City moraine and the Kensal moraine were formed by sublobes of ice that readvanced contemporaneously from the northeast and northwest. It is also possible that the Grace City moraine formed as a recessional feature during the same approximate time that the Kensal moraine was formed by a readvance of a separate lobe of ice to the east. Although no conclusive evidence that solves this problem was observed, the writer agrees with Lemke's and Colton's interpretation that the moraines were probably formed centemporaneously; the writer is not thoroughly convinced, however, that both were formed as a result of a significant readvance of the ice sheet, though this seems probable. The major evidence in support of this interpretation is that, as Lemke and Colton (1958, p. 50) pointed out, no cross-cutting relations are known to exist between the two moraines. In addition, the location of the James River valley and the presence of several kames along the part of the Grace City moraine that parallels the James River valley, may be more easily accounted for if an interlobate development existed in this area.

During the time the Grace City moraine was formed, Pipestem Creek valley served as an important outlet for glacial melt water from the south and southwest part of the ice lobe. If the Grace City and Kensal moraines were formed contemporaneously, the James River valley was a drainageway for melt water from both lobes of ice. After the formation of the Grace City moraine, the ice margin probably retreated to the north-northwest, uncovered a large tract of ground moraine, and locally formed minor recessional washboard moraines. During this retreat, Pipestem Creek valley, and possibly the James River valley, continued to serve as melt-water channels. After the retreat and disintegration of the lobe of ice that formed the Grace City moraine, Pipestem Creek valley may have ceased to function as a melt-water channel. According to Lemke and Colton (1958, p. 51), however, the James River valley later served as a drainageway for glacial melt water during the maximum advance and early deglaciation of the Souris and Leeds ice lobes to the north.

KENSAL MORAINE

The Kensal moraine was formed by a significant readvance of the ice sheet from the northeast. The morainal topography varies greatly in character, but two major units may be recognized: 1) The Kensal moraine, which has a rugged morainal topography; and 2) subdued end moraine that is present on both the proximal and distal sides of the Kensal moraine. The Kensal moraine and the subdued end moraine, however, do not necessarily mark the maximum extent of the ice margin during the readvance (pl. 1). For purposes of clarity, the subdued end moraine will be discussed separately from the Kensal moraine even though it is closely related to it.

This moraine, referred to by Lemke and Colton (1958, p. 50 and fig. 5) as the Kensal moraine, enters the county north of Kensal and trends south-southeast and leaves the county northeast of Spiritwood. The width of the moraine increases from about 3 miles near Kensal to more than 5 miles in the vicinity of Blue Lake, 12 miles to the south. South of the latitude of Blue Lake the proximal margin of the moraine is located in Barnes County.

North of Spiritwood Lake the distal margin of the Kensal moraine is, in general, well defined topographically. An obstructed melt-water channel which parallels the margin of the moraine for much of its length, accentuates the boundary of the feature. South and east of Spiritwood Lake, however, the distal margin is not continuously well defined and the moraine consists of irregularly spaced morainal hills that merge with subdued end moraine. The proximal side of the moraine is difficult to locate because numerous washboard moraines in adjacent areas of subdued end moraine obscure the boundary. Thus the topography along the proximal margin of the moraine is fairly rugged. The average altitude of the subdued end moraine is about 1,515 to 1,520 feet above sea level — significantly lower than the highest parts of the Kensal moraine, which range from 1,550 to more than 1,600 feet above sea level.

The moraine lacks a continuous, well-defined crest and consists of a linear belt of morainal hills intermixed with numerous closed depressions. The altitude of many hills exceeds 1,575 feet above sea level and at places exceeds 1,600 feet above sea level. The highest point, located in the NE¼ sec. 23, T. 142 N., R. 63 W., has an altitude of 1,645 feet above sea level. The high altitudes associated with the moraine in the vicinity of Blue Lake may be explained in part by the overriding of the Buchanan moraine by the younger Kensal moraine. Maximum local relief per square mile exceeds 200 feet, but the average local relief is about 50 to 75 feet per square mile. The rugged topography results partly from the presence of numerous kettles, several stream-eroded valleys, and one obstructed melt-water channel.

South and east of Spiritwood Lake the moraine is not as well defined topographically as it is to the north. Local relief averages 30 to 40 feet per square mile in areas where there are no stream valleys. Subdued end moraine is more extensive than the Kensal moraine in this area.

LANDFORMS ASSOCIATED WITH THE KENSAL MORAINE

Major landforms associated with the Kensal moraine include: 1) Subdued end moraine; 2) a group of ice marginal kames; 3) several glacial melt-water channels, located mainly on the distal side of the moraine; and 4) ground moraine in the northeast corner of the county. The Kensal moraine and these associated landforms represent a morphostratigraphic unit (pl. 1).

SUBDUED END MORAINE. — Subdued end moraine refers to areas that are gentically related to an end moraine, that lack a well-developed morainal topography, and that are characterized by greater local relief than that which is present in adjacent areas of ground moraine. The local relief averages 25 to 30 feet per square mile and is greater where stream valleys cross the areas. Low, isolated morainal hills are common, and slopes are steeper than those associated with ground moraine. Small areas of lower altitude and low relief are within the subdued end moraine; these may resemble ground moraine or may be lacustrine plains. In the northern part of Nogosek Township (T. 144 N., R. 63 W.) is an example of a lacustrine plain located in the moraine.

Linear ridges, conformable to the trend of the Kensal moraine, are present in the subdued end moraine east of Jim Lake on the distal side of the moraine. These ridges are also common in much of the subdued end moraine on the proximal margin of the Kensal moraine. The linear ridges are interpreted as washboard moraines and contribute significantly to the local relief.

ICE-MARGINAL KAMES. — A notable concentration of kames marks the maximum position of the ice sheet that eventually formed the Kensal moraine. One large kame and three smaller kames are situated on the east side of Arrowwood Lake. In addition there are three small kames and two large kames just east of Jim Lake. Grasshopper Hills, in the SE¼ sec. 21, T. 143 N., R. 64 W., contains the largest of these and consists of numerous boulder-strewn hillocks. The hillocks cover about a quarter of a square mile and the highest point is about 100 feet above the average altitude of the surrounding landscape. Some of the hillocks are characterized by a linear trend that is parallel to the strike of the Kensal moraine and that presumably formed at the ice margin. The linear hillocks are similiar to landforms in the two kame complexes in the west part of the county. Grasshopper Hills consists mainly of sand and gravel, although some masses of till are present also. The hillocks are prominent topographically; Kresl (1956) suggests that they may be bedrock composed, at least in part, of Fox Hills Sandstone, but this interpretation has been proved to be incorrect.

Just south of Spiritwood Lake six kames are located in sec. 36, T. 142 N., R. 63 W. and secs. 1, 12 and 13, T. 141 N., R. 63 W. (fig. 20). Farther to the south in secs. 14, 23, and 26, T. 141 N., R. 63 W., are five kames in a linear arrangement in an area of ground moraine, and, when viewed as a group, they resemble a north-south trending esker. These are all part of a closely spaced group of ice-marginal kames that were formed during a readvance of the ice sheet.

FIGURE 20

Large kame located at the margin of the drift deposited by the glacial advance that formed the Kensal moraine. View is west from the east boundary of sec. 1, T. 141 N., R. 63 W.

The kames described above were formed at or near the maximum position of an ice sheet that readvanced to form the Kensal moraine. The presence of the kames marks, in part, the maximum extent of this ice advance and such kames may be characteristic of this phase of glaciation.

MELT-WATER CHANNELS. — A complex system of glacial melt-water channels drains the distal side of the Kensal moraine. Two well-defined melt-water channels, obstructed in part by glacial drift, extend southeast from the vicinity of Arrowwood Lake toward Blue Lake. The valleys, irregular in width, are generally flat bottomed, but closed depressions and depositional mounds of glacial debris are present locally within them. The depressions, some of which contain lakes, indicate that the melt-water channels were probably deeper at one time than they are today. The pits could have formed by the melting of masses of ice that were deposited, along with other glacial debris, in a melt-water channel. If this is true, the channels must have existed before the ice margin overrode their position. The writer believes that the melt-water channel along the distal side of the Kensal moraine was overridden by an ice margin that advanced from the northeast. This event forced the cutting of a second melt-water channel 1 or 2 miles to the west. Continued advance of the ice margin later blocked this second drainageway and glacial melt water was diverted farther west to a position marked by the James River valley. As the ice margin later retreated to the northeast, the overridden channels could not serve as major outlets for melt water because they were filled, at least in part, with glacial debris.

Similiar events are believed to have occurred south of Blue Lake in the drainage system associated with Sevenmile Coulee (fig. 21). As previously stated, Sevenmile Coulee may be divided into upper-middle, and lower sections. The upper section, which extends from sec. 1 to sec. 25 in Fried Township (T. 141 N., R. 63 W.) is narrow and irregular and was formed when the ice margin advanced

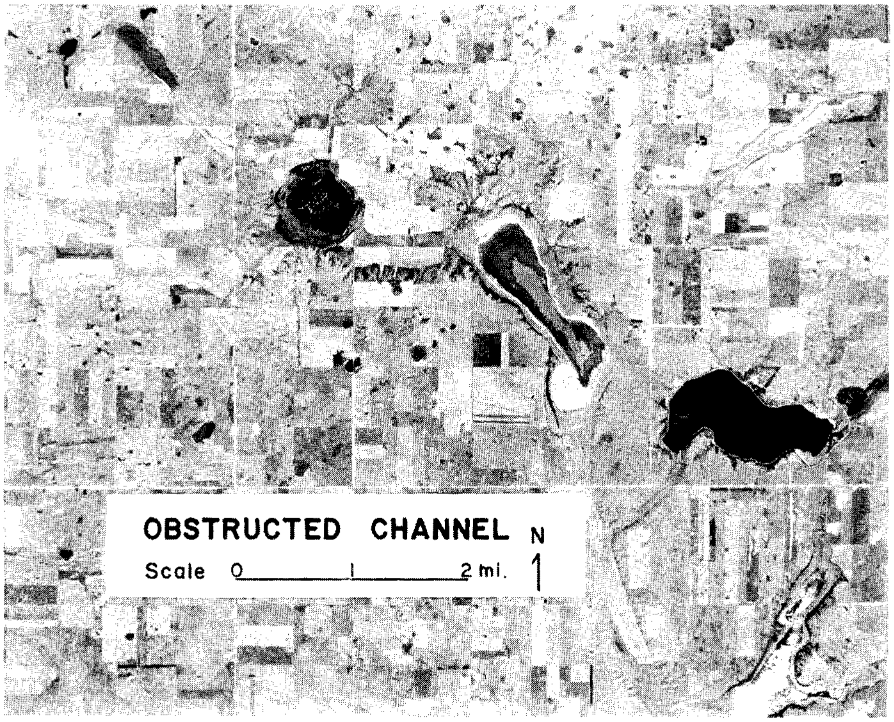


FIGURE 21—Aerial photograph of an obstructed channel marked by several lakes in the east part of the county. Blue Lake occupies the circular depression shown in the north-central part of the photograph. Photograph by the Corps of Engineers.

far enough west to disrupt the drainage in this area. The middle section, which extends from sec. 30 in Fried Township (T. 141 N., R. 63 W.) to sec. 19 in Spiritwood Township (T. 140 N., R. 62 W.), was not markedly affected by the ice advance because the terminal position of the ice margin roughly coincided with the valley. The lower section, which is much wider than either the upper or middle sections, probably did not exist before the readvance of the ice sheet. This part of Sevenmile Coulee probably formed during the time that the ice margin readvanced to block drainage of melt water to the south-southeast into Barnes County by way of an obstructed melt-water channel located southwest of Spiritwood (see Drainage History).

All the melt-water channels described above may have served as drainageways, at least for a short period of time, while the ice margin retreated northeast from its maximum position. In addition, other channels formed during the advance and retreat of the ice margin. Thus, the complex system of melt-water channels on the distal side of the Kensal moraine is the result of a significant rearrangement in the drainage system that was brought about by a readvance of the ice sheet.

Other melt-water channels that formed during or after the time that the ice sheet readvanced to its maximum position include: 1) A narrow gravel-filled valley that trends southwest through Gray Township (T. 142 N., R. 62 W.) toward Spiritwood Lake; 2) a melt-water channel that trends west in northern Rose Township (T. 141 N., R. 62 W.), and 3) a shallow valley that contains significant amounts of glaciofluvial material and that trends southeast from the east border of the county through secs. 25 and 36, T. 140 N., R. 62 W. and secs. 1 and 11, T. 139 N., R. 62 W. to join a large tract of undifferentiated outwash. All these valleys served as outlets for melt water while the ice margin retreated to the northeast and all contain significant amounts of glaciofluvial material.

Ground moraine in the northeast part of the county. — A tract of ground moraine covers about 25 square miles on the proximal side of subdued end moraine in the northeast part of the county. The altitude of the ground moraine ranges, in general, from 1,500 to 1,525 feet above sea level. The surface is gently rolling except for one large, isolated morainal hill along the east border of the county in secs. 11 and 12, T. 144 N., R. 62 W. Sand and gravel deposits are associated with one kame in the NW¼ sec. 16 and with an esker in secs. 10 and 11 in Corinne Township (T. 144 N., R. 62 W.). Sand and gravel are also associated with a lacustrine plain that has its center in sec. 1, T. 144 N., R. 63 W., and extends north into Foster County.

Character of the drift. — The Kensal moraine and the subdued end moraine and ground moraine associated with it are composed mainly of till. No major physical characteristic was observed in exposures that definitely distinguishes the till of the Kensal moraine from other surficial tills in the county. Size analyses of till samples, however, suggest that the till contains more sand and less silt and clay than do other tills in Stutsman County; this variation is not great and is not apparent in the exposures that were examined.

Glaciofluvial materials associated with melt-water channels generally consist of horizontally- and cross-bedded sand and gravel. The lacustrine sediments consist primarily of silt and clay and may be interbedded with some sand.

Thickness of the drift. — The thickness of the glacial drift probably ranges from 100 to 300 feet in much of the area covered by this morphostratigraphic unit. The only known major exceptions to this are the following: 1) In the west-central part of this unit, bedrock crops out at several places along the walls of melt-water channels in the southeast part of Lyon Township (T. 143 N., R. 64 W.), showing that the drift is not very thick in this area; 2) along the east border of the county a deep bedrock valley, filled with glacial drift, trends north-south (Pl. 2) and the glacial drift may exceed 500 feet in thickness along the strike of this buried valley. Probably most of the glacial drift was deposited before the ice advanced to form the Kensal moraine. This is indicated by two exposures in the vicinity of Spiritwood Lake and one south of Spiritwood in which the drift deposited by the last advance of the ice is less than 50 feet thick.

INTERPRETATION. — The Kensal moraine was deposited by a significant readvance of the ice sheet and possibly formed contemporaneously with the Grace City moraine because cross-cutting relations do not exist between the two moraines. Evidence indicating that the Kensal moraine was formed by a significant readvance of the ice sheet includes the following:

1. The Buchanan moraine, formed by an ice margin that retreated to the north, is truncated in Ashland Township (T. 142 N., R. 63 W.) by the Kensal moraine, which was formed by an ice margin that retreated to the northeast.
2. Northeast-trending washboard moraines within the ground moraine in the distal side of the Kensal moraine just west of the middle section and east of the lower section of Sevenmile Coulee are also truncated by low ridges of glacial drift. The trend of the ridges is roughly parallel to the strike of the Kensal moraine.
3. A group of ice-marginal kames marks, at least in part, the maximum position of the ice sheet during the readvance.
4. Obstructed melt-water channels are found only in the east and northeast parts of the county and are best explained by a readvance of the ice.
5. Two exposures along the south side of Spiritwood Lake in sec. 31, T. 142 N., R. 62 W. and one along the east boundary of sec. 11, T. 139 N., R. 62 W. on the north side of a melt-water channel, reveal till overlying water-deposited sediments that in turn overlie an older till. The upper till may have been deposited during the last ice advance, which formed the Kensal moraine. In the two exposures near Spiritwood Lake, the water-deposited sediments have been severely disturbed and masses of the overlying till have been thrust into fluvial and lacustrine sediments, which indicates that the upper till was deposited by a readvance of the ice sheet (figs. 22 and 23).

Because the maximum position of the ice sheet was west of the Kensal moraine, glacial drift was deposited in the form of ice-marginal kames and subdued end moraine on the distal side. In addition, the ice margin overrode at least two glacial melt-water channels and forced a reorganization of the drainage of the area. Major changes in drainage probably included the establishment of the James River valley

FIGURE 22

Lacustrine and fluvial material overlying till. Contortions in the water-deposited sediments were formed by the readvance of the glacier that deposited the Kensal Moraine. The till was deposited prior to the readvance. Exposure is in a man-made cut along the south shore of Spiritwood Lake in the SW¼ sec. 31, T. 142 N., R. 62 W.

FIGURE 23

Close view of the contorted lacustrine sediments shown in figure 22. The face of this exposure strikes northeast and is roughly perpendicular to the long axes of the contortions.

as a major outlet for melt water in the northeast part of the county and the development of the lower section of Sevenmile Coulee.

After the construction of the Kensal moraine, the ice margin eventually retreated to the east and northeast. Subdued morainal topography formed along the proximal margin of the Kensal moraine and several melt-water channels carried melt water away from the ice margin as it retreated. Further retreat of the ice margin uncovered the ground moraine that is located in the extreme northeast part of the county. This retreat marked the final recession of the ice sheet from Stutsman County.

AGE OF THE SURFICIAL DRIFT AND ASSOCIATED LANDFORMS

The discussion of the age of the surficial drift and associated landforms in the county was purposely separated from the previous descriptions of sediment characteristics and topographic forms because of the following factors, which may influence the continuing development of a glacial chronology for North Dakota: 1) Investigations of Pleistocene stratigraphy in North Dakota are in an initial stage, 2) regional correlations with drift sheets recognized by various workers in other areas within or outside the State may be tenuous because the glacial geology of the intervening areas may not be understood, 3) a glacial chronology that is appropriate in another area may not be applicable to North Dakota, 4) at the present time there is some lack of agreement regarding a classification of the Wisconsin Glaciation for the Midwest. The following discussion deals basically with the relative and absolute ages, as far as can be determined, of the surficial sediments and landforms in the county. Possible regional correlations are considered only insofar as they might relate to the problem under consideration.

AGE OF THE SURFICIAL DRIFT WITHIN THE COTEAU DU MISSOURI

According to Lemke and Colton (1958, p. 49 and fig. 3), the Streeter moraine correlates with the B-1 drift border in South Dakota, shown by Flint (1955, fig. 31).

Flint (1955, p. 118) states that the B-1 drift was deposited during a significant readvance of the glacier that occurred after a shrinkage of unkown magnitude in Mankato time. Rau (1962, p. 35) states that in Kidder County, North Dakota, the drift associated with the Streeter moraine apparently overlies Burnstad Drift of Clayton (1961) and that the former is very nearly time equivalent with the latter — that is, the moraine of the Streeter Drift was deposited very shortly after the Burnstad Drift. Lemke and Colton (1958, fig. 3) have tentatively correlated Burnstad Drift in North Dakota with the A-1 advance in South Dakota, which Flint interprets as the maximum position of the ice during Mankato time (Flint, 1955, p. 118, fig. 31). Rau (1962, p. 28) accepts this general correlation by Lemke and Colton but points out that the actual border of the Burnstad Drift in Kidder County may be somewhat different from that interpreted by Lemke and Colton (Rau, 1962, p. 23).

Moir (1958, p. 108-114) and supplement) describes fossil wood within sand and silt that overlie till in Kidder County. A radiocarbon age determination of samples of the wood by the Geochronology Laboratory of the U. S. Geological Survey indicates an age of 11,480±300 years (sample W-542), which correlates closely with an average of dates for the Two Creeks Interstade of Wisconsin time. According to Rau (1962, p. 28), the wood overlies till of Burnstad age. Thus, Burnstad Drift was probably deposited before 11,480±300 years ago, and if Rau (1962, p. 35) is correct, the Streeter moraine was formed a short time after the Burnstad Drift was deposited.

In Stutsman County in a gravel pit in the SW¼ sec. 17, T. 139 N., R. 67 W., thin and finely ribbed pelecypod shells and shell fragments lie in stagnation outwash deposits. The sediments consist of sand and gravel that were deposited by melt water some time after the formation of the Streeter moraine. Numerous shell fragments are found mainly in the coarser sediments but in certain beds of sand, intact clam shells, ranging from very small to about 4 inches in length, are oriented with their long axes roughly parallel to the bedding — some with both valves attached in a closed position. The fragile nature of the shells, their mode of occurrence, and the numerous shell fragments in the coarser sediments indicate that the pelecypods could not have been transported very far and that they may be in place. Thus, the pelecypods must be proglacial and must have been buried in glacial drift as the ice stagnated in the west part of the county.

A radiocarbon age determination of samples of the shells made by the Geochronology Laboratory of the U. S. Geological Survey show that the shells are 11,070±300 years old (sample W-956). This suggests that the Streeter moraine was formed prior to 11,070±300 years ago and that stagnant glacial ice existed in at least parts of the Coteau du Missouri at the approximate time of the Two Creeks Interstade, which is associated with the Michigan Lobe of the ice sheet.

Fragile, but intact and closed pelecypod shells are present also in the upper 24 inches of a dark soil zone containing pebbles and cobbles in the SE¼SE¼ sec. 29, T. 137 N., R. 69 W., immediately east of the proximal margin of the Streeter moraine. The soil zone overlies till that probably was deposited by the ice which formed the Streeter moraine. The life forms must have existed either during the time of glacial stagnation or in ponded water that existed some time after the area was free of ice. A radiocarbon age determination by the Geochronology Laboratory of the U. S. Geological Survey shows that the shells are 9,870±290 years old (sample W-954). This date indicates that the Streeter moraine was formed prior to 9,870±290 years ago and further substantiates the radiocarbon date described above and the subsequent interpretation.[21]

If the radiocarbon dates described above are correct, apparently stagnant glacial ice existed in the west part of the county during at least part of Two Creeks time and the Streeter moraine was formed before 11,070±300 years ago. Furthermore, the nature of the landforms in the west part of the county indicates

[21] Two other samples of carbonaceous material obtained from drift in North Dakota which have been dated by the U. S. Geological Survey are found to be similar in age (samples W-993, 9,900±400; W-1005, 10,050±300) to the pelecypod shells. Both of the radiocarbon age determinations were obtained from wood fragments collected from sediments of glacial Lake Agassiz in the extreme eastern part of the state.

that no readvance of the glacier reached this part of the county after the Streeter moraine was formed. The time of the last glacial advance that overrode the west part of the county is not known. Possibly the last advance predates the final disintegration of the ice by a long period of time. Perhaps the margin of the glacier fluctuated within the Coteau du Missouri for several thousand years, or more, before the ice finally disintegrated, and possibly the rate of ablation was relatively slow in an environment characterized by stagnant ice.

AGE OF THE SURFICIAL DRIFT WITHIN THE DRIFT PRAIRIE

The Millarton, Eldridge, and Buchanan moraines are all interpreted as recessional moraines which were formed while the ice margin retreated from the east part of the county. The Kensal moraine and possibly the Grace City moraine were formed by a significant readvance that post dates the formation of the Buchanan moraine. Topographic and stratigraphic evidence that supports this interpretation has already been described, but the duration of the ice-free period that preceded the readvance is not known. No evidence was discovered to indicate that the ice-free period was long, but the lack of such evidence does not preclude this possibility.

Lemke and Colton (1958, p. 50 and fig. 3) indicate that all the surficial drift in the county is of Mankato age. However, they also point out that Leighton (1957b) interprets the Big Stone moraine in Minnesota to be of Valders age. If the Big Stone moraine correlates with the Kensal moraine, the Two Creeks Interstade should, according to Lemke and Colton, separate the drift that was deposited by the ice sheet when it advanced to form the Kensal moraine from the older drift associated with the Streeter advance. The exact age of the drift of the Kensal moraine was not learned during the course of this study. It is known to post date the age of the Buchanan moraine, and in all probability it predates the age of wood fragments with ages of 10,050±300 (sample W-1005) and 9,900±400 (sample W-993) collected from sediments of glacial Lake Agassiz. The age of the drift associated with the Millarton, Eldridge, and Buchanan moraines post dates the age of the Streeter moraine, which exceeds 11,070±300 years, and predates the age of the Kensal moraine.

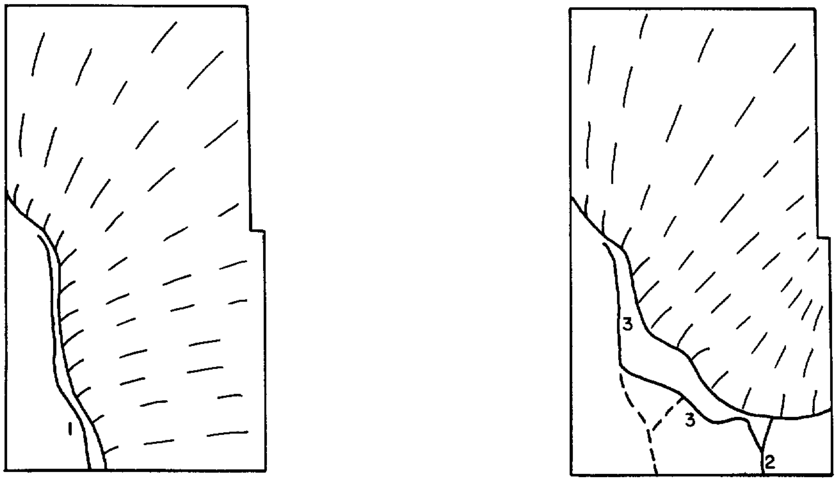
DRAINAGE HISTORY AND RESULTANT TERRACES

It is not possible to determine the exact nature of the drainage conditions that existed prior to the final deglaciation of the county because these have been largely obscured by the deposition of glacial drift. Apparently, however, stream systems that predate the present drainage conditions existed in preglacial and glacial times. Some record of these drainage conditions is revealed in the nature of the bedrock topography and in the character of the sediments that were penetrated by drilling in the county.

Major stream valleys that probably existed in preglacial times and that may have served as drainageways during and between earlier phases of glacial activity include the ancestral Cannonball River valley and the Spiritwood valley. The ancestral Cannonball River valley probably followed one of the three courses shown on plate 2. Spiritwood valley trends north-south along the east border of the county and may be: 1) A northward continuation of the prediversionary Cheyenne River valley noted by Flint (1955, p. 148 and pl. 7), 2) a part of the ancestral Cannonball drainage system, or 3) a part of a valley system that has not been previously recognized.

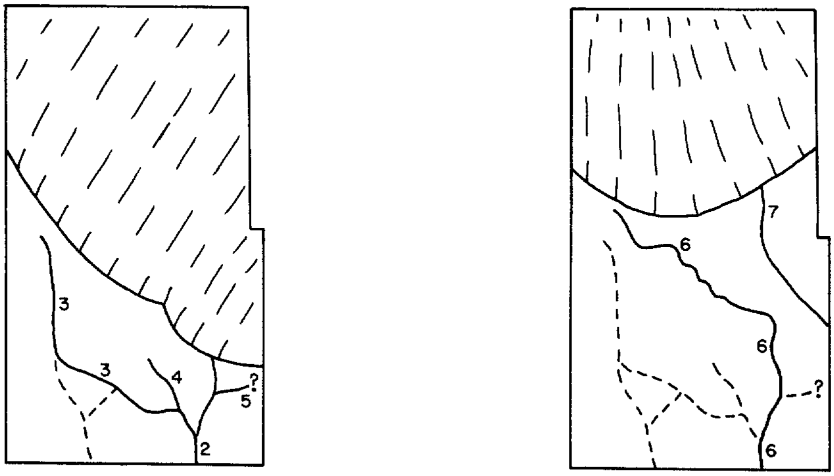
Little is known of the drainage conditions in the county between the time the area was first glaciated and a time prior to the final disintegration of the glacier. It is reasonable to assume, however, that pre-existing drainageways were diverted, obstructed, and buried as a result of glaciation and that new or modified drainage systems were established. Some of the sand and gravel deposits in the subsurface are undoubtedly glaciofluvial sediments that were deposited in valleys

Late Drainage Developme
Stutsman Count



A
Millarton Phase

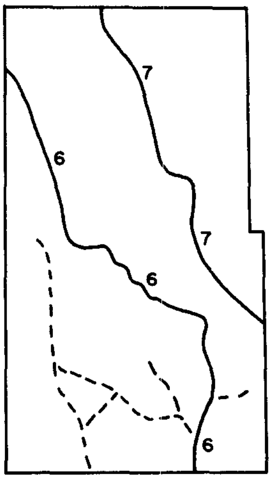
B
Eldridge Phase



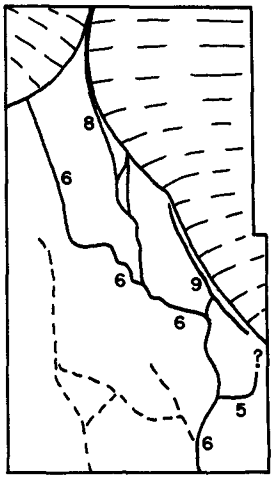
C
Late Eldridge Phase

D
Buchanan Phase

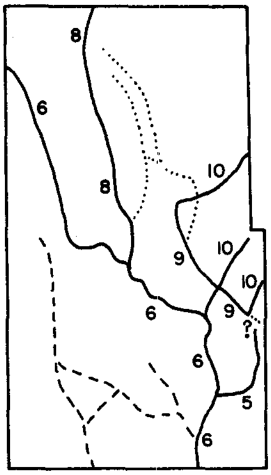
the Eastern Half of
rth Dakota



E
Post Buchanan – Pre Kensal Phase



F
Kensal Phase (assuming Kensal and Grace City moraines were constructed contemporaneously)



G
Post Kensal Phase

L E G E N D

——— Active Meltwater Channel
– – – Abandoned Meltwater Channel
········ Obstructed and Abandoned Meltwater Channel

-N-

1 Minneapolis Flats
2 James River Valley
3 Beaver Creek – Upper Minneapolis Flats Valley
4 Unnamed Tributary to Beaver Creek
5 Streamon Coulee
6 Pipestem – Lower James System
7 Sevenmile Coulee (early stage)
8 Upper James River Valley
9 Sevenmile Coulee (after diversion)
10 Unnamed Tributaries to Sevenmile Coulee

SCALE
10 0 10 20 miles

during Pleistocene time. Available data, however, are not adequate to permit recognition of pre-existing drainage systems and patterns. Extensive drainage systems probably did exist, however, during Pleistocene time prior to the final deglaciation of the county and at least parts of these systems are recorded by linear deposits of sand and gravel that exist below the land surface in the county.

LATE DRAINAGE HISTORY OF THE COTEAU DU MISSOURI

After the glacier formed the Streeter moraine, part of which is located in the extreme southwest part of the county, extensive stagnation of the ice sheet occurred in the area known as the Coteau du Missouri. The ice ablated in place and the melt water probably followed drainageways in and on the surface of the glacier; melt water accumulated in depressions on the surface of the stagnant ice or in low areas on the emerging subglacial surface. In the present topography in the west part of the county, there is a notable absence of either an integrated drainage system or large valleys formed by glacial melt water. This indicates that during the final phases of ice disintegration large amounts of melt water were not available to erode the drift and that much of the melt water that did exist either evaporated or was absorbed by the drift. Furthermore, valley cutting has been negligible since the disappearance of the glacier in this area. As a result, throughout the west part of the county much of the runoff drains to the numerous closed depressions, or potholes, and seeps into the drift or evaporates (fig. 7). Thus, the nature of the landforms combined with a subhumid climate has retarded development of an integrated drainage system in the west part of the county.

LATE DRAINAGE HISTORY IN THE DRIFT PRAIRIE PRIOR TO THE FORMATION OF THE KENSAL MORAINE

While the Millarton moraine was forming, glacial melt water drained south along the flank of the ice sheet by way of Minneapolis Flats (fig. 24, part A). As the ice margin retreated to the north and northeast, the James River valley also served as a major south-trending drainageway in the southeast part of the county (fig. 24, part B). Beaver Creek valley, a tributary to the James River valley, probably formed at about the time that the ice sheet constructed the southern part of the Eldridge moraine (fig. 24, part B). Beaver Creek valley also captured the drainage of Minneapolis Flats at about the same time, and this resulted in a major diversion of drainage in the county (fig. 24, part B).

As the ice margin retreated to the north from the Eldridge moraine, an unnamed melt-water channel formed on the proximal margin of the moraine, some of the melt water from the west flank of the ice sheet drained south by way of Minneapolis Flats and Beaver Creek valley, and the James River valley was lengthened by headward erosion. Streaman Coulee, in the southeast part of the county, may have formed also at this time, although this is not definitely known (fig. 24, part C). Continued retreat of the ice margin toward Buchanan moraine probably resulted in the abandonment of Minneapolis Flats and Beaver Creek valley as glacial melt-water channels. Most of the water probably drained south by way of Pipestem Creek valley and the part of the James River valley south of Jamestown. The segment of the James River valley north of Jamestown probably did not exist at this time, or, if a valley did exist, it was probably a minor tributary valley that bore little resemblance to the present drainageway (fig. 24, part D).

A second melt-water channel located to the east of the lower James-Pipestem system may have formed during this phase of glacial activity. This drainageway, part of which is occupied by Sevenmile Coulee, extends south-southeast through the northeast part of the county and enters Barnes County south of Spiritwood (fig. 24, part D). The character and course of most of the valley have been largely obscured by glacial events that postdate its formation, but the middle part of Sevenmile Coulee is for the most part an unaltered segment of the melt-water channel (fig. 24, part F).[22] Topographic evidence of the former course

---

[22] A previous discussion of Sevenmile Coulee is included in the section on Glacial landforms and their history.

of the channel, which was overridden by the glacier and obstructed by drift, exists both north and south of the middle section of Sevenmile Coulee. A part of the obstructed channel is especially apparent in Ashland Township (T. 142 N., R. 63 W.), where a group of lakes are present in a linear lowland that trends northwest (fig. 21, pl. 1).

After the Buchanan moraine formed, the ice margin retreated an unknown distance to the north. During this retreat Pipestem Creek valley and the northward continuation of the middle section of Sevenmile Coulee were lengthened by headward erosion, and both probably continued to be active as melt-water channels (fig. 24, part E).

DRAINAGE HISTORY DURING AND AFTER THE FORMATION OF THE KENSAL MORAINE

A significant readvance of the ice sheet occurred some time after the ice margin retreated from the Buchanan moraine. This readvance resulted in several drainage diversions that affected Sevenmile Coulee. One of these diversions resulted in the formation of the lower part of Sevenmile Coulee. Before the ice readvanced to form the Kensal moraine, Sevenmile Coulee extended south-southeast, entering Barnes County south of Spiritwood; it did not join the James River valley as it does today (fig. 24, part E). The readvance of the ice from the northeast eventually blocked Sevenmile Coulee somewhere east of Stutsman County. Melt-water must have been ponded in the valley and then spilled over the relatively narrow interfluve to enter the James River valley about 6 miles east-southeast of Jamestown. Some of the melt water may also have drained to the south by way of Streaman Coulee at the same time, but this is not definitely known. Thus, the readvance and subsequent diversion resulted in the establishment of the lower section of Sevenmile Coulee located, in part, in secs. 29, 30 and 31, T. 140 N., R. 62 W. (pl. 1; fig. 24, part F).

The sequence of events described above helps to explain major variations in the form and width of Sevenmile Coulee and a significant drainage anomaly in that valley. The writer believes that the middle section of Sevenmile Coulee was not markedly affected by the readvance of ice which formed the Kensal moraine because the terminal position of the glacier coincided approximately with the location of the valley. However, the upper section of the coulee was overridden by this ice advance, and the irregular and narrow character of this part of the valley may have resulted from blockage and subsequent diversion of melt water by the glacier. Some of the melt water that eroded the upper section of Sevenmile Coulee undoubtedly flowed directly from the ice because the valley ends abruptly in secs. 1 and 2, T. 141 N., R. 63 W. Furthermore, this diversion also may account for the existence of the group of lakes (Sevenmile and Spiritwood Lakes, among others) that occupies low areas in the overridden valley. It is also note-worthy that the lower section of Sevenmile Coulee widens abruptly to twice the width of the middle section. As there is no noticeable change in the gradient of the valley or in the character of the material into which the valley has been eroded, the variation in width is probably related to an abrupt increase in the amount of melt water that drained south in this part of Sevenmile Coulee. The sources of the melt water were: 1) Water draining south by way of the upper and middle sections of the coulee, 2) water draining north-northwest in the former south-southeast-trending drainageway that was blocked by the glacier, and 3) water draining southwest by way of a stream valley that presently drains Rush Island Lake in sec. 9, T. 140 N., R. 62 W. (pl. 1). This glacial melt water may also have served to widen the James River valley south of the point where it is joined by Sevenmile Coulee.

After the readvance, the margin of the glacier retreated to the northeast but glacial melt water continued to drain to the James River by way of the newly established lower part of Sevenmile Coulee. The unnamed melt-water channel located in secs. 20, 28, and 33, T. 140 N., R. 62 W., which formerly served as the lower part of Sevenmile Coulee in the county, was obstructed by glacial drift, and the drainage in the valley was permanently reversed. As a result, the intermittent stream occupying this valley drains north-northwest in an opposite direction to the regional drainage, thus forming a barbed drainage pattern in Spiritwood Township (T. 140 N., R. 62 W.).

Another drainage diversion, believed to postdate the formation of lower Sevenmile Coulee, occurred in the northeast part of the county as the ice that formed the Kensal moraine reached its terminal position. The glacier advanced and overrode the northwest-trending extension of Sevenmile Coulee; it then diverted the melt water to a new drainageway that extended south to join the Pipestem-lower James system at the site of Jamestown. The drainage diversion probably took place in at least two stages. First, the pre-existing southeast-trending valley was blocked by the advancing ice and a new channel, nearly parallel to the overridden valley, was established 1 to 2 miles to the west (pl. 1). Then, further advance of the glacier also blocked this newly established drainageway and the melt water was again diverted; it then eroded the part of the James River north of Jamestown (fig. 24, part F). By coincidence the newly established course of the upper James River trended south across a large bedrock high but one with little or no topographic expression (pls. 1 and 2). Downcutting in the valley has resulted in the removal of overlying drift and in the partial intrenchment of the valley into the underlying Pierre Shale.

When the melt water formed the segment of the James River valley north of Jamestown, a significant amount of water was diverted away from Sevenmile Coulee. The melt water that drained south in the upper James River valley joined the water in Pipestem Creek valley and probably widened the James River between the site of Jamestown and Sevenmile Coulee. The James River valley was not widened abruptly south of the point where it is joined by Sevenmile Coulee because the role of Sevenmile Coulee as a melt-water channel had greatly diminished at this time.

As the ice that formed the Kensal moraine retreated northeast, all the overridden drainageways were freed of ice, but their channels were obstructed, at least in part, by glacial drift. As a result, the newly established lower section of Sevenmile Coulee and upper James River valley continued to serve as melt-water channels even though the latter was established across a bedrock high that Pipestem and Sevenmile Coulee had largely avoided (fig. 24, part F).

During the final retreat of the ice margin from the county, three west-trending tributaries carried melt water to Sevenmile Coulee (fig. 24, part G). These tributaries drain to the coulee by way of Rush Island Lake, Sevenmile Lake, and Spiritwood Lake. The latter may have existed in some form before, or contemporaneously with, the ice advance that resulted in the formation of the Kensal moraine because till overlies glaciofluvial sediments along the south side of the valley in the NW¼ sec. 14, T. 142 N., R. 62 W. The other two tributary valleys were probably formed with the final retreat of the ice margin.

Both the James River valley and Pipestem Creek valley continued to serve as outlets for melt water as the ice margin retreated an unknown distance from Stutsman County. According to Lemke and Colton (1958, p. 51-52, fig. 4), a significant readvance of the glacier occurred after the formation of the Kensal and Grace City moraines and this readvance resulted in the construction of the Martin, Heimdal, Cooperstown, and Wahpeton moraines. Pipestem Creek was probably inactive as a melt-water channel during this readvance, but the James River valley again served as a melt-water channel for a short period of time. The James River valley not only served as an outlet for melt water from the readvancing glacier, but also as a temporary outlet for glacial Lake Souris (Lemke and Colton, 1958, p. 51). As the ice margin once again retreated, the Sheyenne River temporarily captured the drainage of glacial Lake Souris and the James River valley became inactive as a melt-water channel (Lemke and Colton, 1958, p. 51-52).

TERRACES ASSOCIATED WITH GLACIAL MELT-WATER CHANNELS

Terraces are common in the James River valley south of Jamestown, Pipestem Creek valley south of the Grace City moraine, Beaver Creek valley, Streaman Coulee, and Sevenmile Coulee (pl. 1). The terraces are present at various altitudes and consist of glaciofluvial sediments, till, or a combination of both. With the exception of terraces in the middle and upper sections of Sevenmile Coulee, the landforms resulted from erosion by running water. The terrace forms in the middle and upper sections of Sevenmile Coulee are interpreted as kame terraces and thus are depositional rather than erosional features.

Because of the significant drainage diversions that occurred in the county and because of the lack of information regarding specific glacial events that took place after the ice margin retreated, interpretation and correlation of the terrace forms are difficult. In some places, such as in the lower James River valley, two or more groups of terraces are present at different altitudes in a single valley. In other valleys, such as Beaver Creek valley, it was not possible to definitely differentiate separate groups of terraces. The following is a description of the terraces that were observed in Stutsman County and, where possible, a discussion of the relation of the terraces to the drainage development.

TERRACES ASSOCIATED WITH THE LOWER JAMES RIVER VALLEY AND PIPESTEM CREEK VALLEY. — Scattered remnants of a high terrace, about 75 feet above the floodplain of the James River, are found in the east-trending part of the valley in sec. 2, 4, 11, 13, and 14, T. 140 N., R. 63 W. (pl. 1). The terraces, composed of glaciofluvial sediments, may be remnants of an early phase of valley development associated with the lower James-Pipestem system, which is believed to have been established as the ice margin retreated north from the Eldridge moraine. However, because the terraces are few in number and widely spaced, they reveal little of former drainage conditions.

Glaciofluvial material exposed in two gravel pits (one in the NE¼ sec. 14, T. 139 N., R. 63 W., and the other in the SE¼ sec. 2, T. 139 N., R. 63 W.) ranges widely in grain size and pebble types. In the gravel pit in sec. 14 at least 22 feet of fine gravel is characterized by cut-and-fill structures. Analysis of samples from this site indicates that about 16 per cent of the material is granules and pebbles and 84 per cent is sand (table 4, column A). Furthermore, shale and other sedimentary rock types represent 39 and 48 per cent respectively of all pebbles in the sample (table 5, column A).[23] However, in the gravel pit located in sec. 2, very coarse gravel, in which cobbles are abundant, is most common. Analysis of samples from this deposit reveals that 68 per cent of the sample was larger than coarse sand (table 4, column B). In addition, sedimentary rock types, excluding shale,

TABLE 4. — Grain sizes in samples of glaciofluvial material

U. S. SIEVE SERIES		SAMPLES Percentage by weight (rounded off to nearest per cent)							
Number	Size (mm.)	A[1]	B[1]	C[2]	D[2]	E[2]	F[3]	G[3]	H[4]
2	8	3	43	24	16	35	7	37	27
5	4	6	14	20	14	11	7	22	17
10	2	7	11	27	17	12	14	17	19
18	1	12	11	14	22	15	27	13	18
35	1/2	38	12	7	18	17	29	9	12
60	1/4	34	5	3	9	7	14	2	4
120	1/8	t	2	2	3	2	2	t	1
230	1/16	t	1	1	t	t	t	t	1
Pan		t	1	1	t	1	t	t	1

t (trace) equals less than one-half of one per cent.

Source of Samples: *

[1] Samples from high terraces within the James valley
[2] Samples from low terraces within the James and Pipestem valleys
[3] Samples from terraces within upper and middle Sevenmile Coulee
[4] Sample from low terrace within lower Sevenmile Coulee

* For exact location of sample sites see supplement to tables 4 and 5.

---

[23] Size and pebble analysis of samples of glaciofluvial material from all terraces was computed on the basis of weight.

TABLE 5. — Pebble types in samples of glaciofluvial material

PEBBLE TYPES	Percentage by Weight (to nearest per cent)							
	A[1]	B[1]	C[2]	D[2]	E[2]	F[3]	G[3]	H[4]
Shale	39	5	11	19	11	22	69	45
Other sedimentary (mainly carbonates)	48	54	45	38	60	52	16	39
Igneous and metamorphic	13	41	44	43	29	26	15	16

Source of Samples: *

[1] Samples from high terraces within the James valley
[2] Samples from low terraces within the James and Pipestem valleys
[3] Samples from terraces within upper and middle Sevenmile Coulee
[4] Sample from low terrace within lower Sevenmile Coulee

* For exact location of sample sites see supplement to tables 4 and 5, below:

* *Locations of glaciofluvial samples.*

A. NE¼ sec. 14, T. 139 N., R. 63 W.
B. SE¼ sec. 2, T. 139 N., R. 63 W.
C. SW¼ sec. 26, T. 140 N., R. 64 W.
D. SW¼ sec. 5, T. 139 N., R. 63 W.
E. NW corner sec. 7, T. 138 N., R. 62 W.
F. SE¼ sec. 13, T. 141 N., R. 63 W.
G. SE¼ sec. 31, T. 141 N., R. 62 W.
H. SE¼ sec. 19, T. 140 N., R. 62 W.

and igeneous and metamorphic stones constitute 54 and 41 per cent, respectively, of the pebble sample and shale is relatively uncommon (table 5, column B).

Low terrace forms, which average 20 to 30 feet higher than the adjacent floodplain, are common in the James River valley south of Jamestown and in Pipestem Creek valley south of the Grace City moraine (pl. 1). These low terraces are not present either in Pipestem Creek valley north of the Grace City moraine or in the James River valley north of Jamestown.[24] Most of the low terraces consist of glaciofluvial material and they are interpreted as remnants of a dissected valley train. The terraces are present on both sides of the valleys and are especially common along the inner side of a curving stream course.

No exposures reveal till overlying glaciofluvial sediments in the low terraces. This indicates that the sand and gravel were deposited during or after the retreat of the ice margin from the Eldridge moraine. Logically, the low terraces were formed some time after the high terraces described previously. In addition, the valley train from which the terraces were formed must have been deposited some time previous to the retreat of the ice margin from the Grace City moraine, because the terraces can be traced only as far north as the distal margin of that moraine. Pits, formed by the melting of buried blocks of ice, are found on those terraces that are located in the immediate vicinity of the distal margin of the Grace City moraine. This indicates that probably the valley train was formed, at least in part, at the time of the Grace City moraine. The absence of low terrace forms north of the Grace City moraine and in the part of the James River valley north of Jamestown suggests that the deposition of the valley train predates the formation of the part of Pipestem Creek north of the Grace City moraine and predates the drainage diversion that resulted in the establishment of the upper James River valley north of Jamestown. Thus, there is abundant evidence that the valley train from which the terraces were later formed was deposited after the ice retreated from the Eldridge moraine, prior to the retreat of the ice margin from the Grace City moraine, and probably before the drainage diversion that resulted in the formation of the upper James River valley north of Jamestown. The time at which the valley train was dissected to form the low terraces is more difficult to determine. Obviously the terraces post date the formation of the valley

---

[24] Landforms below the water level of the Jamestown Reservoir north of the Jamestown Dam were mapped on the basis of aerial photographs and topographic maps that predate the formation of the reservoir.

train and they are known to have been formed before the final abandonment of Pipestem Creek valley as a glacial melt-water channel because valley development since that time has been negligible.[25]

Most of the terrace forms in Pipestem Creek valley and the James River valley south of Jamestown consist of poorly sorted glaciofluvial sediments. Analysis of samples from three locations indicates an average of 40 per cent sand, 59 per cent granules and pebbles, and the remander silt and clay (table 4, columns C, D, and E). Carbonates and other sedimentary rock types, excluding shale, are most abundant among the pebbles, followed by igneous and metamorphic stones. Shale constitutes about 14 per cent of the pebble samples. Cobbles and boulders are rare in these deposits.

TERRACE ASSOCIATED WITH THE UPPER PART OF THE JAMES RIVER VALLEY. — North of the latitude of Jamestown, the James River valley narrows abruptly and for much of its extent is intrenched into bedrock. Only one terrace with its center in secs. 18, 19, and 20, T. 143 N., R. 64 W., is located in this part of the valley. The terrace surface, underlain by glaciofluvial material, averages 45 feet higher than the adjacent valley bottom. The exact origin of the single terrace and the thickness of the sand and gravel are not known. The terrace probably records an early stage of valley development associated with the drainage diversion that formed the valley. One explanation for the absence of numerous terraces in the upper James River valley is that the drainageway formed some time after the deposition of a valley train in the lower James River valley.

TERRACES ASSOCIATED WITH BEAVER CREEK VALLEY AND STREAMAN COULEE. — The terraces in both Beaver Creek valley and Streaman Coulee have an average altitude that ranges from 20 to 50 feet higher than the valley bottoms and most of the terraces are probably composed of glaciofluvial sediments. The origin of the terraces is not definitely known, but the form and characteristics of the sediments indicate that they are erosional remnants of an early period of valley development that occurred during or after the retreat of the ice margin from the area.

TERRACES ASSOCIATED WITH SEVENMILE COULEE. — Sevenmile Coulee may be divided into upper, middle and lower sections on the basis of variations in valley characteristics.[26] Terraces are present in all three sections, but there are significant variations between the character of the terraces in the upper and middle sections of the coulee and the character of those in the lower section.

The terraces in both the upper and middle sections of Sevenmile Coulee are composed of sand and gravel and range from 10 to 20 feet higher than the adjacent valley bottom. They are found on both sides of the valley but do not oppose one another. The sediments associated with the terraces in both the middle and upper sections of the coulee were probably deposited by glacial melt water from the ice that constructed the Kensal moraine; this is suggested because terraces are present in the upper section of Sevenmile Coulee, which was formed as a result of a drainage diversion during the time of this ice advance, and because till is not known on or within the terraces as would be expected if they had existed previous to this ice advance.

The terraces may be either remnants of an extensive deposit of sand and gravel that has been partially dissected or kame terraces. If the former is true, sand and gravel must have been deposited by melt water from the ice that formed the Kensal moraine and then must have been dissected at a later date. Inasmuch as Sevenmile Coulee last functioned as a glacial melt-water channel during the retreat of the ice from the Kensal moraine, dissection of the sand and gravel in the valley would have to have occurred either during the retreat of the ice margin or

---

[25] Factors indicating that the valley development has been negligible since it served as a glacial melt-water channel include, among others, the underfit character of the stream occupying the valley, the youthful character of drainage in areas adjacent to the valley, the absence of significant stream intrenchment in the valley, the subhumid climate that prevails in the area, and especially the absence of terrace forms within Pipestem Creek valley north of the Grace City moraine.

[26] For discussion see Glacial Landforms and Their History and previous comments in this section on Drainage History.

after the time the valley ceased to serve as a melt-water channel. Both possibilities are unlikely because valley development appears to have been negligible after drainageways in the county ceased to serve as melt-water channels and because Sevenmile Coulee ends abruptly in secs. 1 and 2, T. 141 N., R. 63 W., which indicates that this part of the valley could only have been formed by melt water running directly off glacial ice. In this area, however, terrace forms are not present and this negates the possibility that the sand and gravel were dissected as the ice margin retreated to the northeast (pl. 1).

If the glaciofluvial terraces in upper and middle Sevenmile Coulee are not erosional remnants of a more extensive deposit that has been dissected, they are probably kame terraces. Evidence to support this interpretation follows:

1. The maximum position of the ice advance that formed the Kensal moraine coincides roughly with the location of the upper and middle sections of the coulee (pl. 1). This situation is favorable for the formation of kame terraces.
2. Steep, well-defined slopes, generally mark the face of the terraces.
3. There is a significant variation in the grain size of the sediments which comprise the terraces, and cobbles and boulders are common in some of the deposits.
4. The location of all the terraces may be satisfactorily explained if they are interpreted as kame terraces.

Samples of glaciofluvial sediments from the terraces were collected at two sites, one in the upper section and the other in the middle section of the coulee. The sample from the upper part of the coulee consisted of 72 per cent sand and 28 per cent granules and pebbles (table 4, column F). Sedimentary rock types, excluding shale, constituted more than 50 per cent of the pebbles in the sample (table 5, column F). The sample from the middle part of the coulee consisted of 24 per cent sand and 76 per cent granules and pebbles (table 4, column G). Furthermore, 69 per cent of the pebbles consisted of shale (table 5, column G). Observation of several exposures and the samples described above indicate a high degree of variability in grain size and rock types in the sediments that underlie the terraces in the middle and upper sections of Sevenmile Coulee.

Terraces in the lower section of Sevenmile Coulee are composed of till, glaciofluvial sediments, or sand and gravel that overlie till. Two terraces are underlain by till. One is in secs. 19 and 30, T. 140 N., R. 62 W., and the second extends south from sec. 7, T. 139 N., R. 62 W. into part of the James River valley. Both terraces are about 50 feet higher than the adjacent valley bottoms and decrease in altitude from north to south, as does the altitude of the adjacent valley floodplain. Both terraces are interpreted as erosional features; they were probably formed during the time of the drainage diversion that formed the lower section of Sevenmile Coulee.

A second group of terraces, lower than those described above, have an average altitude that is about 30 feet higher than the stream in Sevenmile Coulee. The terraces are on both sides of the coulee and are underlain, at least in part, by sand and gravel. At several locations along the stream in sec. 31, T. 140 N., R. 62 W., till underlies the glaciofluvial sediments, and the present stream is slightly intrenched into the till.

Sample analysis of glaciofluvial material from a gravel pit located in the SE¼ sec. 19, T. 140 N., R. 62 W. shows that 36 per cent of the material is sand and 63 per cent is granules and pebbles (table 4, column H). Shale cobbles are abundant in this exposure and five large carbonate boulders have been uncovered. Forty-five per cent of the pebbles in the sample consists of shale (table 5, column H).

The sediments of the low terraces in the lower part of Sevenmile Coulee were probably deposited during and (or) shortly after the drainage diversion that formed this valley. Intrenchment of the stream in the valley probably occurred as a result of lowering of the local base level, the James River. To the north, in the middle and upper sections of the coulee, the stream is not intrenched to the same extent. This stage of valley cutting probably occurred as the ice margin retreated to the northeast.

Selected References

Alden, W. C., 1924, Physiographic development of the northern Great Plains: Geol. Soc. America Bull. 35, p. 385-423.

————————, 1932, Physiography and glacial geology of eastern Montana and adjacent areas: U.S. Geol. Survey Prof. Paper 174, 133 p.

American Commission on Stratigraphic Nomenclature, 1961, Code of stratigraph nomenclature: Am. Assoc. Petroleum Geologist Bull., v. 45, p. 645-665.

American Geological Institute, 1960, Glossary of geology and related sciences, 2nd ed., 325 p. and suppl.

Anderson, S. B., 1953, North Dakota Geol. Survey circ., no. 11, 9 p.

————————, 1953, North Dakota Geol. Survey Circ. no. 15, 7 p.

Anteys, Ernst, 1939, Modes of retreat of the Pleistocene ice sheet: Jour. Geology, v. 47, p. 503-508.

Aronow, Saul, 1959, Drumlins and related streamline features in the Warwick-Tokio area, North Dakota: Am. Jour. Sci., v. 257, p. 191-203.

Baillie, A. D., 1951, Dept. Mines and Nat. Res. Pub. 50-1.

Bakken, W. E., 1960, The surficial geology of north-central Kidder County, North Dakota: Univ. North Dakota unpub. thesis, 93 p.

Bayrock, L. A., 1958a, Glacial geology Alliance-Brownfield district, Alberta: Alberta Research Council Prelim. Rept. 57-2, 56 p.

————————, 1958b, Glacial geology Galahad-Hardisty district, Alberta: Alberta Research Council Prelim. Rept. 57-3, 35 p.

Benson, W. E., 1952, Geology of the Knife River area, North Dakota: U.S. Geol. Survey Open File Rept., 323 p.

Bonneville, J. W., 1961, The surficial geology of southern Logan County, North Dakota: Univ. North Dakota unpub. thesis, 87 p.

Branch, J. R., 1947, The geology of the Flora Quadrangle: North Dakota Geol. Survey Bull. 22, 35 p.

Bretz, J. H., 1943, Keewatin end moraines in Alberta: Geol. Soc. America Bull., v. 54, p. 31-52.

Budge, C. E., 1946, Bibliography of the geology and natural resources of North Dakota: North Dakota Research Found. Bull. 1, 214 p.

Caine, T. A., and Kocher, A. E., 1904, Soil Survey of Jamestown area: North Dakota Agri. Coll. Survey 2nd Bienn. Rept., p. 87-111.

Chamberlin, T. C., 1883, Preliminary paper on the terminal moraine of the second glacial epoch: U.S. Geol. Survey 3rd Ann. Rept., p. 393-400.

Charlesworth, J. K., 1957, The Quaternary Era with special references to its glaciation: London, Edward Arnold, Ltd., 2 v., 1700 p.

Christiansen E. A., 1956, Glacial geology of the Moose Mountain area, Saskatchewan: Saskatchwan Dept. Mineral Resources Rept. 21, 35 p.

————————, 1959, Glacial geology of the Swift Current area, Saskatchewan: Saskatchewan Dept. Mineral Resources Rept. 32, 62 p.

————————, 1960, Geology and ground-water resources of the Qu'-Appelle area, Saskatchewan: Saskatchewan Research Council Geol. Div. Rept. no. 1, 53 p.

————————, 1961, Geology and ground-water resources of the Regina area, Saskatchewan: Saskatchewan Research Council Geol. Div. Rept., no. 2, 72 p. and 3 pls.

Chmelik, James, 1960, Pleistocene geology of northern Kidder County, North Dakota: Univ. North Dakota unpub. thesis, 63 p.

Clayton, Lee S., 1960, Tills of Kidder County: North Dakota Acad. Sci. Proc., v. 14, p. 25-32.

————————, 1961, Late Wisconsn Mollusca from ice-contact deposits in Logan County, North Dakota: North Dakota Acad. Sci Proc., v. 15, p. 11-18.

Coleman, A. P., 1926, Ice ages recent and ancient: New York, Macmillan Co., 296 p.

————————, 1941, The last million years: Toronto, Toronto Univ. Press, ed. by George F. Kay, 216 p.

Crandell, D. R., 1950, Revision of Pierre Shale in central South Dakota: Am. Assoc. Petroleum Geologist Bull., v. 34, p. 2337-2346.

Daly, R. A., 1935, The changing world of the ice age: New Haven, Yale Univ. Press, 271 p.

Demorest, Max, 1943, Ice sheets: Geol. Soc. America Bull, v. 54, p. 363-400.

Dennis, P. E. Akin, P. D., and Jones, L., 1949, Ground water in the Wyndmere area in Richland County, North Dakota: North Dakota Ground Water Studies no. 13, p. 1-59.

Derbyshire, Edward, 1958, The identification and classification of glacial drainage channels from air photographs: Geografiska Annaler, v. 40, p. 188-195.

Dyson, J. L., 1952, Ice-ridged moraines and their relation to glaciers: Am. Jour. Sci., v. 250, p. 204-211.

Easker, D. G., 1949, The geology of the Tokio Quadrangle: North Dakota Geol. Survey Bull. 24, 35. p.

Elson, J. A., 1957a, Lake Agassiz and the Mankato-Valders problem: Sci., v. 26, no. 3281, p. 999-1002.

————————, 1957b, Origin of washboard moraines (abs.): Geol. Soc. America Jour., v. 68, p. 1721.

————————, 1958, Pleistocene history of southwestern Manitoba: North Dakota Geol. Survey Midwestern Friends of the Pleistocene 9th Ann. Field Conf. Guidebook, p. 62-73.

Farnham, R. S., 1956, Geology of the Anoka sand plain: Geol. Soc. American Field Trip no. 3 Guidebook, p. 53-64.

Fenneman, N. M., 1931, Physiography of western United States: New York, McGraw Hill Book Co., p. 72-79.

————————, 1938, Physiography of eastern United States: New York, McGraw Hill Böok Co., 714 p.

Fisher, S. P., 1952, The geology of Emmons County, North Dakota: North Dakota Geol. Survey Bull. 26, 47 p.

Flint, R. F., 1928, Eskers and crevasse fillings: Am Jour. Sci, v. 15, p. 410-416.

————————, 1929, The stagnation and dissipation of the last ice sheet: Geog. Rev. v. 19, p. 256-289.

————————, 1930, The glacial geology of Connecticut: Connecticut Geol. and Nat. History Survey Bull. 47, 294 p.

————————, 1932, The deglaciation of the Connecticut River valley: Am Jour. Sci., v. 24, p. 152-156.

————————, 1943, Growth of North American ice sheet during the Wisconsin age: Geol. Soc. America Bull. 54, p. 325-362.

————————, 1945, Glacial map of North America: Geol. Soc. America Spec. Paper 60, pts. 1, 2.

————————, 1949a, Leaching of carbonates in glacial drift and loess as a basis for age correlation: Jour. Geology, v. 57, p. 297-303.

————————, 1949b, Pleistocene drainage diversions in South Dakota: Geografiska Annaler, v. 31, p. 57-74.

————————, 1955, Pleistocene geology of eastern South Dakota: U.S. Geol. Survey Prof. Paper 262, p. 1-173.

————————, 1957, Glacial geology and the Pleistocene epoch: New York, John Wiley and Son, Inc., 589 p.

Flint, R. F., and Rubin, Meyer, 1955, Radiocarbon dates of pre-Mankato events in eastern and central North America: Sci., v. 121, p. 649-658.

Frye, J. C., and Leonard, A. B., 1953, Definition of time line separating a glacial and interglacial age in the Pleistocene: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 11, p. 2581-2586.

Frye, J. C., and Willman, H. B., 1960, Classification of the Wisconsinan stage in the Lake Michigan glacial lobe: Illinois Geol. Survey Circ. 285, 16 p.

————————, 1962, Note 27 — Morphostratigraphic units in Pleistocene stratigraphy: Am. Assoc. Petroleum Geologists Bull. v. 46, P. 112-113.

Goldthwait, J. W., 1938, The uncovering of New Hampshire by the last ice sheet: Am. Jour. Sci., v. 36, p. 345-372.

Gravenor, C. P., 1955, The origin and significance of prairie mounds: Am. Jour. Sci., v. 253, p. 475-481.

Gravenor, C. P., and Ellwood, R. B., 1957, Glacial geology Sedgewick district, Alberta: Alberta Research Council Prelim. Rept. 57-1, 43 p.

Gravenor, C. P., and Kupsch, W. O., 1959, Ice disintegration features in western Canada: Jour. Geology, v. 67, p. 48-64.

Gwynne C. S., 1942, Swell and swale topography of the Mankato lobe of the Wisconsin drift plain in Iowa: Jour. Geology, v. 50, p. 200-208.

————, 1951, Minor moraines in South Dakota and Minnesota: Geol. Soc. America Bull. v. 62, p. 233-250.

Hainer, J. L., 1956, The geology of North Dakota: North Dakota Geol. Survey Bull. 31, 46 p.

Hansen, Miller, 1956, Geologic map of North Dakota: North Dakota Geol. Survey.

————, 1958, A summary of the Pleistocene and recent history of the Devils Lake area: North Dakota Geo. Survey Midwestern Friends of the Pleistocene 9th Ann. Field Conf. Guidebook, p. 80-84.

Hard, H. A., 1929, Geology and water resources of the Edgeley and LaMoure Quadrangles, North Dakota: U.S. Geol. Survey Bull. 801, 90 p.

Hartshorn, J. H., 1958, Flowtill in southeastern Massachusetts: Geol. Soc. America Bull., v. 69, p. 477-482.

Holland, F. D., 1957, Guidebook for geologic field trip in the Jamestown area, North Dakota: North Dakota Geol. Survey Misc. Ser., no. 7, 16 p.

Holmes, C. D., 1941, Till fabric: Geol. Soc. America Bull., v. 52, p. 1299-1354.

————, 1947, Kames: Am. Jour. Sci. v. 245, p. 240-249.

————, 1949, Glacial erosion and sedimentation: Geol. Soc. America Bull., v. 60. p. 1429-1436.

Hoppe, Gunar, 1952, Hummocky moraine regions with special reference to the interior of Norrbotten: Geografiska Annaler, v. 34, p. 1-72.

Hoppe, Gunar, and Schytt, Walter, 1953, Some observations on fluted moraine surfaces: Geografiska Annaler, v. 35, p. 105-115.

Horberg, L., and Anderson, R. C., 1956, Bedrock topgraphy and Pleistocene glacial lobes in central United States: Jour. Geology, v. 64, p. 101-116.

Howard, A. D., 1946, Caliche in glacial chronology (abs.): Geol. Soc. America Bull., v. 57, p. 1204.

————, 1960, Cenozoic history of northeastern Montana and north-western North Dakota with emphasis on the Pleistocene: U.S. Geo. Survey Prof. Paper 326, 107 p.

Howard, A. D., Gott, G. B., and Lindvall, R. M. 1946, Late Wisconsin terminal moraine in northwestern North Dakota (abs.): Geol. Soc. America Bull., v. 57 no. 12, pt. 2, p. 1204-1205.

Huxel, C. J., Jr., 1961, Artesian water in the Spiritwood buried valley complex, North Dakota: U.S. Geol. Survey Prof. Paper 424-D, p. 179-181.

King, P. B., 1951, The tectonics of middle North America-middle North America east of the Cordilleran system: Princeton, New Jersey, Princeton Univ. Press, 203 p.

Kline, V. H., 1942, *Stratigraphy of North Dakota:* Am. Assoc. Petroleum Geologist Bull., v. 26, no. 3, p. 336-379.

Kresl, R. J., 1955, Geology of the Eldridge Quadrangle, North Dakota: North Dakota Geol. Survey Bull. 28, p. 85-91.

————, 1956, Geology of the lower Pipestem Creek area, North Dakota: North Dakota Geol. Survey Rept. Inv., no. 25.

Lahee, F. H., 1952, Field Geology: New York, McGraw Hill Book Co., 883 p.

Laird, W. M., 1941 Selected deep well records: North Dakota Geol. Survey Bull. 12, 31 p.

————,1956, Guide for geologic field trip in northeastern North Dakota: North Dakota Geol. Survey Bull. 30, p. 1-20.

Laird, W. M., and Hansen, Miller, 1957, Guidebook for geologic field trip in the Valley City area, North Dakota: North Dakota Geol. Survey Misc. Ser., no. 1, p. 1-10.

Lawrence, D. B., and Elson, J. A., 1953, Periodicity of deglaciation in North America since the late Wisconsin maximum: Geografiska Annaler, v. 35, p. 83-104.

Leighton M. M., 1957a, The Cary-Mankato-Valders problem: Jour. Geology, v. 65, no. 1, p. 108-111.

——————, 1957b, Radiocarbon dates of Mankato drift in Minnesota: Sci. v. 125, p. 1037-1038.

——————, 1958, Important elements in the classification of the Wisconsin glacial stage: Jour. Geology v. 66, no. 3, p. 288-309.

——————, 1959a, Book review: Jour. Geolgy, v. 67, no. 5, p. 598-600.

——————, 1959b, Stagnancy of the Illinoian glacial lobe east of the Illinois and Mississippi Rivers: Jour. Geology v. 67, no. 3, p. 337-344.

Lemke, R. W., 1958a, Glacial history of the Souris River lobe, North Dakota: North Dakota Geol. Survey Midwestern Friends of the Pleistoecne 9th Ann. Field Conf. Guidebook, p. 85-92.

——————, 1958b, Narrow linear drumlins near Velva, North Dakota: Am. Jour. Sci., v. 256, p. 270-283.

——————, 1960, Geology of the Souris River area, North Dakota: U.S. Geol. Survey Prof. Paper 325, 138 p.

Lemke, R. W., and Colton, R. B., 1958, Summary of the Pleistocene geology of North Dakota: North Dakota Geol. Survey Midwestern Friends of the Pleistocene 9th Ann. Field Conf. Guidebook, p. 41-57.

Lemke, R. W., and Kaye, C. A., 1958, Two tills in the Donnybrook area, North Dakota: North Dakota Geol. Survey Midwestern Friends of the Pleistocene 9th Ann. Field Conf. Guidebook, P. 93-98.

Leverett, Frank, 1922, What constitutes the Altamont moraine (abs.): Geol. Soc. America Bull. v. 33, p. 102-103.

Leverett, Frank, with contr. by Sardeson, F. W., 1932, Quaternary geology of Minnesota and parts of adjacent states: U.S. Geol. Survey Prof. Paper 161, 149 p.

Leonard A. G., 1912, Geology of south-central North Dakota: North Dakota Geol. Survey 6th Bienn. Rept., p. 21-99.

——————, 1916a, Pleistocene drainage changes in western North Dakota: Geol. Soc. America Bull., v. 27, p. 295-334.

——————, 1916b, The pre-Wisconsin drift of North Dakota: Jour. Geol., v. 24, p. 521-532.

——————, 1917, The geological history of North Dakota: North Dakota Univ. Quart. Jour., v. 7, no. 3, p. 229-235.

——————, 1919a, The geology of North Dakota: Jour. Geology, v. 27, no 1, p. 1-27.

——————, 1919b, The surface features of North Dakota and their origin: North Dakota Univ. Quart. Jour., v. 9, no. 3, p. 209-219.

Mawdsley, J. B., 1936, Washboard moraines in the Opawica-Chibougamau area, Quebec: Royal Soc. Canada Trans., 3rd ser., sec. 4, v. 30, p. 9-12.

Meek, F. B., and Hayden, F. V., 1862, Description of new Lower Silurian, Jurassic, Cretaceous, and Tertiary fossils collected in Nebraska territory: Philadelphia Acad. Natl. Sci. Proc., v. 13, p. 419, 420, 422, 424.

Moir, D. R., 1958, Occurence and radio-carbon date of Coniferous wood in Kidder County: North Dakota Geol. Survey Midwestern Friends of the Pleistacene 9th Ann. Field Conf. Guidebook, p. 108-114.

Moir, D. R., Hansen, Miller, and Lemke, R. W., 1958, Occurrence and radio-carbon date of coniferous wood in Kidder County (unpub. supp.): North Dakota Geol. Survey Midwestern Friends of the Pleistocene 9th Ann. Field Conf. Guidebook, 3 p.

Nelson, L. B., 1955, North Dakota Geol. Survey Circ. no. 198, 5 p.

Nikiforoff, C. C., 1947, The life history of Lake Agassiz, alternative interpretation: Am. Jour. Sc., v. 245, p. 205-239.

Paulson, Q. F., 1952, Geology and occurence of ground water in the Streeter area, Stutsman, Logan, and Kidder Counties North Dakota: North Dakota Ground-Water Studies no. 20, 73 p.

Perry, E. S., Montana in the Geologic Past: Mont. Bur. Mines and Geology, Bull. 26, Fig. 11.

Rand McNally, 1957, Commercial atlas and marketing guide: New York Rand McNally, p.332-337.

Rau, J. L. et. al., 1962, Geology and ground-water resources of Kidder County, North Dakota, Part I Geology: North Dakota Geol. Survey Bull. 36, 70 p.

Rice C. M., 1957, Dictionary of geologic terms: Ann Arbor, Michigan, Edwards Bros., 465 p.

Roth, F. J., and Zimmerman, J. J., 1955, Physiography of North Dakota: North Dakota Geol. Survey Bull. 28, p. 83-84.

Rothrock, E. P., 1946, The surface portion of the James basin in South Dakota: South Dakota Geol. Survey Rept. Inv. 54, 21 p.

Ruhe, R. V., 1950, Graphic analysis of drift topographies: Am. Jour. Sci., v. 248, p. 435-443.

__________, 1952, Topgraphic discontinuities of the Des Moines lobe: Am. Jour. Sci., v. 250, p. 46-56.

Ruhe, R. V., Rubin, Meyer, and Scholtes, W. H., 1957, Late Pleistocene radiocarbon chronology in Iowa: Am. Jour. Sci., v. 255, no. 10, p. 671-689.

Schmitz, E R., and Kresl, R. J.. 1955, Postglacial warping in North Dakota: North Dakota Geol. Survey Bull. 28, p. 92-97.

Sharp, R. P., 1953, Glacial features of Cook County, Minnesota: Am. Jour. Sci., v. 251, no. 12, p. 855-883.

Simpson, H. E., 1929, Geology and ground-water resources of North Dakota: U.S. Geol. Survey Water-Supply Paper 598, 311 p.

Smith, Carole, 1954a, North Dakota Geol. Survey Circ., no. 51, 4 p.

__________, 1954b, North Dakota Geol. Survey Circ., no. 64, 6 p.

Stalker, A. M., 1960a, Ice-pressed drift forms and associated deposits in Alberta: Canadian Geol. Survey Bull. 57, 38 p.

__________, 1960b, Surficial geology of the Red Deer-Stettler map-area, Alberta: Canadian Geol. Survey Mem. 306, 140 p.

Strassberg, M., 1953, North Dakota Geol. Survey Circ., no. 32, 9 p.

Tetrick, P. R., 1949, Glacial geology of the Oberon Quadrangle: North Dakota Geol. Survey Bull. 23, 35 p.

Thwaites, F. T., 1943, Pleistocene of part of northeastern Wisconsin: Geol. Soc. America Bull., v. 54, p. 87-144.

__________, 1959, Outline of glacial geology: Ann Arbor, Michigan, Edward Bros., 133 p.

Todd, J. E., 1896, The moraines of the Missouri Coteau and their attendant deposits: U.S. Geol. Survey Bull. 144, p. 13-59.

__________, 1914, The Pleistocene history of the Missouri River: Sci., v. 39, p. 263-274.

__________, 1923, Is the channel of the Missouri River through North Dakota of Tertiary origin: Geol. Sci. America Bull., v. 34, p. 469-494.

Townsend, R. C., and Jenke, A. L., 1951, The problem of the origin of the Max moraine of North Dakota and Canada: Am. Jour. Sci., v. 249, p. 842-858.

Towse, Donald, 1952, Subsurface geology of south-central North Dakota: North Dakota Geol. Survey Bull. 27, 23 p.

Univ. Wisconsin Agr. Experiment Station, 1960, Soils of the north central region of the United States: Bull. 544, North Central Regional Pub. 76, p. 80-81,114.

U.S. Department of Commerce, 1955, Climatic summary of the United States: supp. for 1931 through 1952, North Dakota, no. 28.

Upham, Warren, 1896, The glacial Lake Agassiz: U.S. Geol. Survey Mon. 25, 658 p.

Warren, C. R., 1952, Probable Illinoian age of part of the Missouri River: Geol. Soc. America Bull., v. 63, p. 1143-1156.

Washburn, A. L., 1956, Classification of pattern ground and review of suggested origins: Geol. Soc. America Bull., v. 67, p. 823-865.

Wentworth, C. K., 1922, A scale of grade and class terms for clastic sediments: Jour. Geology, v. 30, p. 377-392.

White, G. W., 1932, an area of glacier stagnation in Ohio: Jour. Geology, v. 40, p. 238-258.

Willard, D. E., 1909, Jamestown-Tower folio no. 168: Geol. Atlas of the U.S., Geol. Survey, 9 p.

Willard, D. E., and Erickson, M. B., 1904, A survey of the Coteau of the Missouri: North Dakota Agr. Coll. Survey 2nd Bienn. Rept., p. 17-27.

Williams B. J., 1960, Glacial geology of south-central Kidder County, North Dakota: Univ. North Dakota unpb. thesis, 91 p.

Wilmarth, M. G., 1938, Lexicon of geologic names of the United States: U.S. Geol. Survey bull. 896, pts. 1 and 2, 2396 p.

Winters, H. A., 1960, The late Plesitocene geomorphology of the Jamestown area, North Dakota: Northwestern Univ. unpub. Ph. D. thesis, 144 p.

——————, 1961, Landforms associated with stagnant glacial ice: Prof. Geog., v. 13, p. 19-23.

Wright, H. E., 1956, Sequence of glaciation in eastern Minnesota: Geol. Soc. America Guidebook, Field Trip no. 3, eastern Minnesota, p. 1-24.

——————, 1957a, Radiocorbon dates of Mankato drift in Minnesota: Sci., v. 125, p. 1038-1039.

——————, 1957b, Stone orientation in Wadena drumlin field, Minnesota: Geografiska Annaler, v. 39, no. 1, p. 19-31.

Wright, H. E., and Rubin, Meyer, 1956, Radiocarbon dates of Mankato drift in Minnesota: Sci., v. 124, p. 625-626.

Wright, W. B., 1937, The Quaternary ice age: London, Macmillan Co., Ltd., 478 p.

Zumberge, J. H., 1952, The lakes of Minnesota — their origin and classification: Minnesota Geol. Survey Bull. 35, 99 p.

Zumberge, J. H., and Wright, H. E., 1956, The Cary-Mankato-Valders problem: Geol. Soc. America Guidebook, Field Trip no. 3 glacial geol., eastern Minnesota, p. 65-81.