1966

Surficial geology of northern Griggs County, North Dakota

LaVerne C. Rude
University of North Dakota

Appendix III

This abstract of a thesis submitted by LaVerne C. Rude in partial fulfillment of the requirements for the Degree of Master of Arts in the University of North Dakota is hereby approved by the Committee under whom the work has been done.

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SURFICIAL GEOLOGY OF NORTHERN GRIGGS COUNTY, NORTH DAKOTA

LaVerne C. Rude

ABSTRACT

Griggs County, situated in the Western Lake section of the Central Lowland province, covers an area of 720 square miles in east-central North Dakota. The surface of the county is mantled with three, or possibly four Pleistocene drift sheets, separated by outwash deposits. These drift sheets lie unconformably on the Cretaceous Pierre Shale which is exposed in the Sheyenne River valley and the Binford Hills. Because the drift sheets have similar lithologic and physical characteristics, and are all late Wisconsin in age, they fulfill the requirements for a lithostratigraphic unit and are being considered for designation as part of the Pleistocene Lostwood Formation.

As the late Wisconsin glacier receded and thinned in east-central North Dakota, it became controlled by topographic highs, and lobation occurred. One of these lobes, the Leeds, retreated across Griggs County, depositing the McHenry-I, McHenry II, Cooperstown, and Luverne end moraines during temporary stillstands. When the Leeds lobe retreated from the Cooperstown end moraine position, a large block of ice became detached and a complex of eskers, kames, and kettles

was formed. As the ice terminus reached the North Viking end moraine position, the Girard Lake spillway of glacial Lake Souris came into existence, causing meltwater to flow into Griggs County and excavate the Sheyenne River valley.

In western Griggs County, a large buried valley, the Spiritwood aquifer, occurs at the base of the Lostwood Formation. It is filled with outwash sediments that are a potential source of large quantities of ground water.

SURFICIAL GEOLOGY OF NORTHERN GRIGGS COUNTY
NORTH DAKOTA

by

LaVerne C. Rude

Ph.B., with major in Geology, University of North Dakota, 1964

A Thesis
Submitted to the Faculty
of the
University of North Dakota
in partial fulfillment of the requirements
for the Degree of
Master of Arts

Grand Forks, North Dakota

June

1966

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John R. Reid
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LaVerne C. Rude

ABSTRACT

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SURFICIAL GEOLOGY OF NORTHERN GRIGGS COUNTY, NORTH DAKOTA

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INTRODUCTION

Purpose

The purpose of this paper is to describe and discuss the glacial geology and the Pleistocene stratigraphy of northern Griggs County, an area covering 360 square miles in east-central North Dakota. The research was conducted under the auspices of the North D kota Geological Survey during the 1965 field season. This report, when combined with a study of southern Griggs County, which is in preparation, will be published as a Bulletin of the North Dakota Geological Survey.

Primary objectives of this study were: (1) to provide a detailed geologic map of the area, (2) to describe the glacial history and the Pleistocene stratigraphy, (3) to examine the relationship of the glacial geology to ground water conditions, (4) to determine the location and extent of gravel, sand, and other natural resources of the area, and (5) to construct a lithologic map which both delineates the sediments and illustrates the topographic and drainage conditions of the county.

Previous Work

The most recent published summary of North Dakota Pleistocene geology is by Lemke, Laird, Tipton, and Lindvall (1965). A more comprehensive study was published by Lemke and Colton in 1958 and a Preliminary Glacial Map of North Dakota was completed in 1963 by Colton, Lemke, and Lindvall. In the latter study the drift in Griggs County is concluded to be post-Cary maximum in age and to correlate with Flint's (1955) Mankato substage in South Dakota.

No detailed geologic work has yet been published for Griggs County, but Bluemle (1965) has described the glacial geology of Eddy and Foster Counties immediately west of Griggs County, and Block (unpublished Doctor's thesis, University of North Dakota) has described the glacial geology of northern Barnes County which lies immediately to the south. Other studies in the area include those by Branch (1947), Easker (1949), and Tetrick (1949) which describe the glacial geology of three fifteen-minute quadrangles that extend into northern Eddy County. The glacial geology of the Devils Lake region and along the Sheyenne River has been described by Aronow (1957, 1963). The glacial geology of Stutsman County, south of Foster County, has been described by Winters (1963). Studies in nearby areas presently in preparation include those by James C. Merritt on the glacial geology of southern Griggs County, by John P. Bluemle on the glacial geology of Traill County, and one by Jack Kume and D.E. Hansen on the glacial geology of Grand Forks County.

Methods of Study

Northern Griggs County was mapped during the 1965 field season by making automobile traverses along each section road and noting the composition of the sediment from augered holes and road cuts; where no roads were present, the section line was traversed on foot. The augered holes ranged from 2.5 to 6.5 feet in depth, with an average depth of about 4.0 feet. T.E. Kelly of the United States Geological Survey in Grand Forks, North Dakota, supplied the well logs and John P. Bluemle of the North Dakota Geological Survey supplied the missile site data.

Auger holes were drilled and the sediment was examined every one-half mile, while samples for detailed lithologic analysis were collected on a two-mile grid. Where a lithologic or topographic change was obvious, additional samples were taken. Complex areas, areas with unusual features, gravel pits, and artificial excavations, were critically examined and sampled.

The collected data were plotted directly on 1963 county road maps, scale 1:63360, prepared by the North Dakota State Highway Department. Aerial photographic stereopairs, scale 1:63360, taken in 1952, were used extensively in the mapping. In addition to these stereopairs, aerial photographs, scale 1:24000, and United States Geological Survey quadrangle maps, scale 1:24000, with a contour interval of five feet, were used as an aid in refining boundaries, identifying landforms, and delineating drainage basins.

The determination of sediment color, pebble lithology, and grain size was accomplished in the field as well as in the laboratory. The wet color of the sediment was determined in the field by comparison with the Standard Rock Color Chart (Goddard, and others, 1951). The dry color was determined in the laboratory by comparison with the same color chart. Pebble lithology data were determined by either of two methods. In the first method, a coarse and a fine pebble fraction were separated by dry sieving in the field, using sieves with one-half and one-fourth inch openings.[1] In the second method, the gravel was separated from a given till sample by standard wet-sieving in the laboratory. In both cases, the pebbles were examined and identified as to rock type in the laboratory. Detailed lithologic studies (gravel, sand, silt and clay ratio) were completed by pipette analysis, using the North Dakota Geological Survey Standard Procedure A-65, November 1965 (unpublished).

Acknowledgments

I wish to express my appreciation to Dr. John R. Reid, my Graduate Committee Chairman who accompanied me into the

[1] Coarse is herein defined as larger than one-half inch in diameter and fine is between one-fourth and one-half inch in diameter.

field, offered many helpful suggestions, rendered critical evaluation, assisted with and guided the preparation of this report. Special thanks are also extended to Dr. Wilson M. Laird, Committee member, who, as State Geologist, provided field expenses, salary, and incentive for this study. Dr. Edwin A. Noble, also a Committee member, accompanied me into the field on several occasions, encouraging me with my work and rendering many helpful suggestions and criticisms.

Dr. Lee Clayton, Department of Geology, provided valuable field and mapping assistance, developed the technique of lithologic mapping of glacial deposits in North Dakota, for which he provided an outline, and kindly submitted to numerous questions and discussions on the many aspects of this report.

I also wish to thank Mr. James C. Merritt, who introduced me to glacial mapping, worked with me in the field, and collaborated in the preparation of this report. Mr. John P. Bluemle graciously provided the missile site data for Griggs County and mapped adjacent Eddy and Foster Counties.

Mr. Tim E. Kelly, United States Geological Survey, kindly supplied well data for Griggs County. Large aerial photographs (scale 1:24000) and soils maps were supplied by personnel from the Soil Conservation Service at Cooperstown, North Dakota.

In addition to these individuals, I wish to express my thanks to the residents of northern Griggs County who

graciously allowed access to their property and showed an interest in the work that was being accomplished.

GEOGRAPHY

General

Northern Griggs County is located in east-central North Dakota; it is bordered on the west by Eddy and Foster Counties, on the north by Nelson County, and on the east by Steele County (Figure 1). It contains 360 square miles in townships 146 to 148 north and ranges 58 to 61 west. Most of the county is situated between 98°00' and 98°30' west longitude and 47°15' and 47°40' north latitude.

In 1960, the population of Griggs County was 6,317. Cooperstown, the county seat and largest town, is located in southern Griggs County and had a 1960 population of 1,424. Only one village was given individual census status in the northern one-half of the county; this was Binford, with a population of 261. The villages of Jessie and Mose were not listed. Of the total 1960 county population of 6,317, approximately 1,800 resided in the northern half of Griggs County. This figure represents a population density of about five persons per square mile and is a decrease of about eight percent over the 1950 census figure.

The only hard-surfaced roads in northern Griggs County are State Highways 1 and 32 which run north-south. State Highways 45 and 65 also cross the area and even though they are classified as all-weather gravel roads, scattered segments become nearly impassable when wet. Except where sloughs and hilly topography exist, gravelled section roads are fairly evenly distributed throughout the area. These roads range from excellent graded roads to tractor trails and most are passable by field vehicles in dry weather. A spur or branch line of the Northern Pacific Railway crosses the county, serving the villages of Jessie, Binford, and Mose.

Climate

Thornthwaite (1940, plate 1) classifies the climate of Northern Griggs County as dry subhumid, first (cool) mesothermal, with short cool summers and little or no water surplus in any season. At Cooperstown, the average annual temperature is 40°F, while the average January and July temperatures are 3°F and 68°F respectively. About 70 percent of the average annual precipitation of 18.19 inches falls as rain during the period April through August. The greatest annual rainfall ever recorded at Cooperstown was 28.63 inches in 1941 and the least was 9.85 inches in 1917. In 1918, 3.08 inches of rainfall fell in one 24-hour period (Bravendick, 1952). The growing season averages about 124 days at Cooperstown.

The prevailing wind direction is from the northwest in all months except June and August when southeasterly winds predominate. Average wind movement throughout the year is 10 miles per hour and is strongest in the winter months.

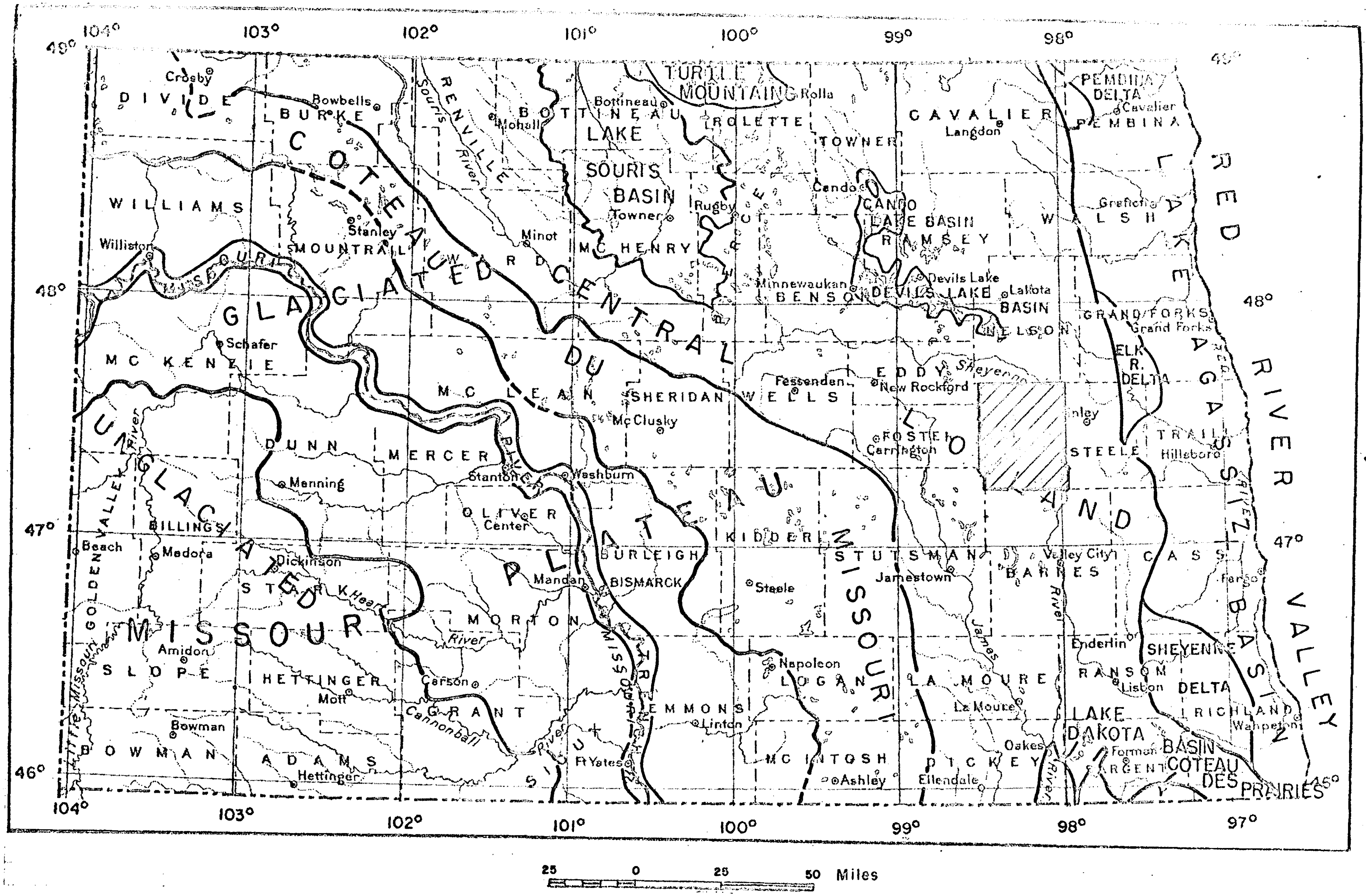

Figure 1. Index map showing the location of Griggs County and the physiographic subdivisions of North Dakota (after Lemke and Colton, 1958, Figure 1).

Soil

All soils in northern Griggs County belong to the Chernozem great soil group. The generalized soils map (plate 3) divides those soils into six major categories, but ignores the thickness of the soil layer and the associated slopes. The categories include (1) loams and clay loams, (2) sandy loams and loams with sandy substrata, (3) (3) sandy loams and loams with gravelly substrata, (4) loams and clay loams with alkali subsoil, (5) soils of valley sides and associated bottom lands, and (6) fresh water marsh. By far the most prominent of these soils are the loams and clay loams. Very little alkali soil is present in the area and the soils are usually very productive when sufficient moisture is available and the slopes are not too steep.

Native Vegetation

The area is part of a transition zone in which tall grasses of the more humid east and short prairie grasses of the western steppe occur. Oak and cottonwood trees are present along streams, particularly in the valley of the Sheyenne River. Buckbrush or Wolfberry (Symphoricarpos occidentalis) is abundant in the northwest portion of the area and is especially characteristic of the collapsed end moraine deposits.

DESCRIPTIVE AND PHYSICAL GEOLOGY

Topographic Units

Introduction

Griggs County is in the Drift Plains District of the Western Lake (Young Drift) Section of the Central Lowland Province (Fenneman and Johnson, 1946, and Bluemle, 1965, Figure 1). Physiographically, northern Griggs County can be further subdivided into the northwestern hills, the southwestern plains, the central rolling plains, the Sheyenne valley, and the eastern plains (Figure 2).

Northwestern hills

This area is bordered on the south by the McHenry-I end moraine, on the east by the Cooperstown end moraine, and on the north and west by the county line. The McHenry-Cooperstown end moraine complex, which has slopes in excess of seven degrees, covers about two-thirds of this area. In addition to linear and collapsed outwash features, the complex contains many small kettles and a kettle chain. With the exception of a meltwater channel and its associated terraces, the remainder of area is composed of ground moraine. Because of the numerous kames, eskers, valley trains, and kettle lakes, which characterize the ground moraine, it has rolling to hilly topography. The Bald Hill Creek drainage basin, with its few, small tributaries and its steep valley slopes, is the only part of the area that has integrated drainage. The remainder has internal drainage.

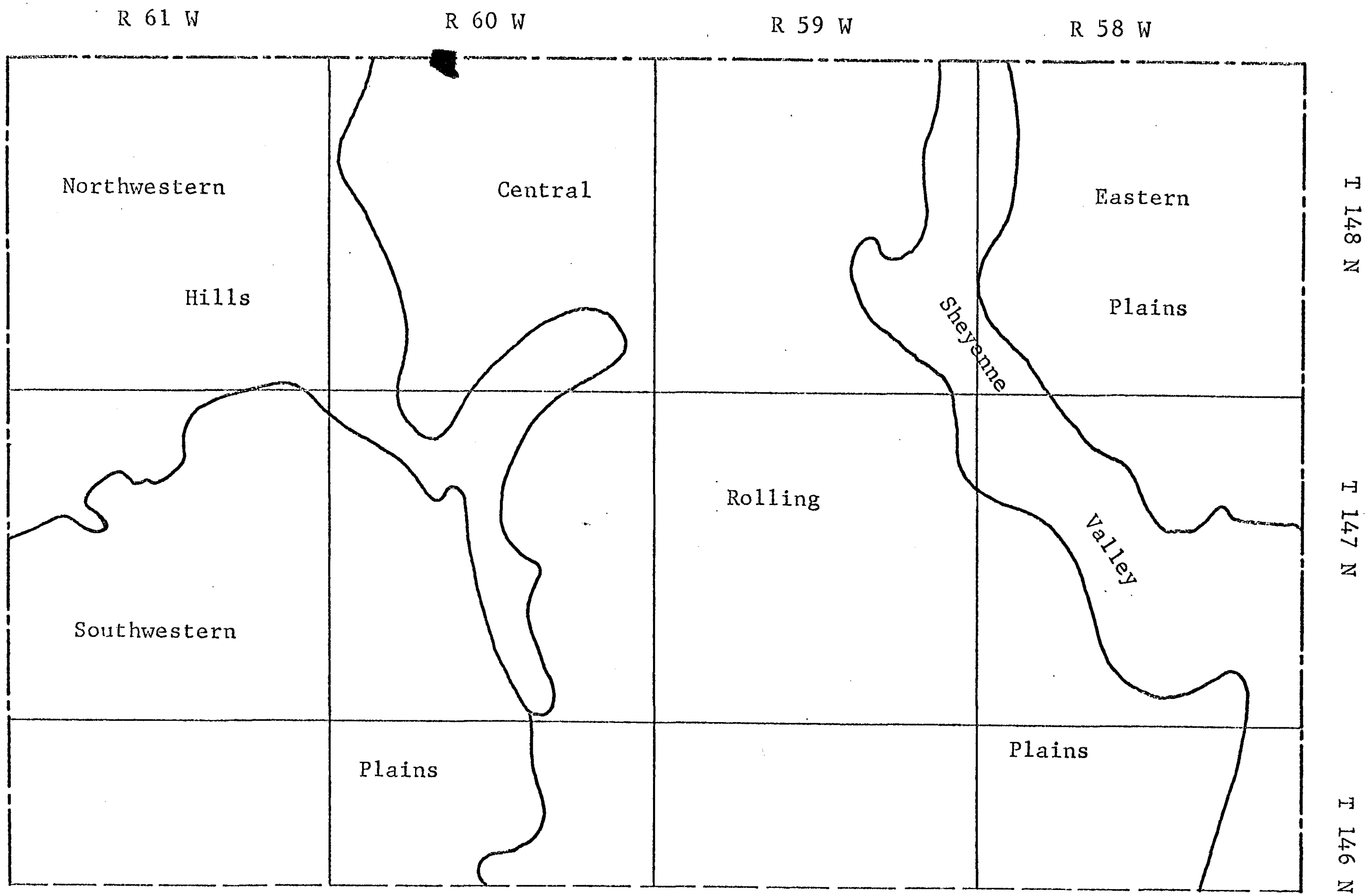

Figure 2. Sketch map showing the physiographic-topographic subdivisions of northern Griggs County.

Southwestern plains

This area is bordered on the north by the McHenry-I end moraine and on the east by the Cooperstown end moraine. On the west and south, it is arbitrarily bounded by the county line and North Dakota State Highway 7, respectively. Although the area is typified by flat to undulating topography, scattered hills in the north and east have slopes in excess of seven degrees. These hills are kames and eskers which are surrounded and covered by outwash. Two exposures of ground moraine occur in the northwest and the southwest corners of this area. The northwest exposure contains kames, eskers, and kettle lakes, while the southwest is barren of such features. With these few exceptions, it is a large fan-shaped outwash plain which contains no constructional features. Bald Hill Creek, with its few associated tributaries and low valley slopes, is the only part of the area with integrated drainage.

Central rolling plains

This area is bordered on the west by the Cooperstown end moraine and on the east by the Sheyenne valley. It is bounded by the county line on the north and by North Dakota State Highway 7 on the south. Covering about one-half of northern Griggs County, it is the largest and most variable of the physiographic-topographic units. It is an undulating area of ground moraine which contains numerous drumlins, rock drumlins, kames, eskers, esker swarms, kettle lakes, kettle chains, valley trains, and an outwash plain. In some parts of the area, the constructional features are so abundant that the topography is rolling to hilly. Figure 3 shows the characteristic hilly topography which exists in the southern portion of this area. Along the eastern margin, bordering the Sheyenne valley, there is an extensive outwash deposit which covers the ground moraine. At many locations, however, the buried constructional features associated with the ground moraine are clearly discernible beneath the thin mantle of sand. With the exception of two ephemeral streams in the northern one-half of this area which drain narrow, low-relief valleys, drainage is nonintegrated.

Sheyenne valley

This area actually contains two physiographic-topographic units. One is the undulating flood plain and associated terraces of the river and the other is the steep valley sides. With the exception of the terraces and a few indistinct meander scars, the river flood plain contains only one feature that merits specific attention. This feature is a large island located in sections 23, 24, 25 and 26, T. 147 N., R. 58 W. It rises very abruptly from the flood plain and reaches a maximum height of 100 to 110 feet. The feature is either a bedrock island in the ancestral Sheyenne river, mantled with till, or it is a large remnant of till which may have been deposited in the valley at the time of glaciation.

Terraces of the Sheyenne River occur on both sides of the valley. They form a step-like progression from the river to the canyon walls and have average heights of 50, 60, 70 and 100 feet above the present flood plain. One of the

Figure 3. Esker swarm in Section 22 T. 146 N., R. 59 W. showing hilly topography. View looking south-southwest.

terraces not associated with the valley walls is located on the eastern side of the large island described previously. It rises about 50 feet above the flood plain. Another mid-channel terrace is only about 20 feet high and occurs in sections 22 and 23, T. 147 N., R. 58 W. The sides of the Sheyenne valley are very steep and highly dissected. Although some talus occurs on the lower slopes, relatively undisturbed Pierre Shale crops out throughout most of the 140 vertical feet of exposure. The entire Sheyenne valley has integrated drainage.

Eastern plains

This area is bounded on the west and south by the Sheyenne valley and on the north and east by the county line. It is characterized by undulating to rolling topography, although it is hilly in a few scattered locations. The area is fairly equally divided between ground moraine and end moraine. Although the end moraine is locally more hilly than the ground moraine (Figure 4), the difference is slight and the best way to delineate the end moraine is by slough density; the end moraine contains an average of 14 sloughs per square mile, while the ground moraine has less than one slough per square mile. The area is characterized by an almost complete lack of constructional features and only three small outwash plains and a few kettle chains are present. With the exception of one small stream channel, which extends from the northern county line to the Sheyenne valley, the area has nonintegrated drainage.

Figure 4. Rolling to hilly surface of the Luverne end moraine. Looking east from the Southeast corner, Sec. 18, T. 148 N., R. 57 W., Steele County, North Dakota.

Hydrologic Units

Introduction

One major stream, the Sheyenne River, flows south across eastern Griggs County. It is the only permanent stream of the area and is contained in a large valley.

Bald Hill Creek, which bifurcates in west-central Griggs County, is the only other important stream in the area. It is a small, ephemeral stream which is situated in a relatively large valley. Small, shallow ephemeral streams and stream channels are abundant and well distributed throughout the study area.

Lakes and sloughs are prominent in northern Griggs County but their distribution is generally random. The areas of highest concentration are those underlain by the loam unit of the Lostwood Formation (page 40) which possesses undulating (1° to 4° slopes) to rolling 4° to 7° slopes) topography. Conversely, lakes and sloughs are characteristically absent from the sand or gravel units of the Lostwood Formation, regardless of slope angle.

Streams

Sheyenne River

The Sheyenne River originates in Sheridan County, flows eastward across Eddy County, then southward through Griggs and Barnes Counties. In Ransom County, it curves northeastward and joins the Red River north of Fargo. It is entrenched in a large, deep bedrock valley which averages three-fourths of a mile wide and 140 feet deep in northern Griggs County. Within this valley, the river flows in a meandering channel which averages about 50 feet in width. Normal summer water depth in the middle of the channel is six to eight feet.

The present Sheyenne trench transects the Heimdal end moraine in southern Benson County and northwestern Eddy County. In addition, it crosses the McHenry end moraine in north central Eddy County. For this reason, either the initial trench, or a pre-Wisconsin trench which had become filled or partially filled with glacial drift, must have been carved in post-Heimdal-McHenry time. Because data are lacking either to prove or disprove the existence of an earlier channel, it will be assumed that the ancestral Sheyenne River began in post-Heimdal-McHenry time. Aronow (1963, page 872) attributes the cutting of the Sheyenne trench to the draining of glacial Lake Souris. He concluded that, when the Leeds lobe retreated from the Heimdal end moraine position to the North Viking end moraine position (Figure 20, page 88), the Girard Lake spillway of glacial Lake Souris was exposed. This allowed meltwater to excavate the Sheyenne trench. Lake Souris continued to drain through the Sheyenne River until the ice had retreated to a position north of the Turtle Mountains in southwestern Manitoba. When the ice front reached this point, glacial Lake Souris found a new outlet through the Pembina trench and its drainage through the Sheyenne River was terminated. Although there are no reliable C^{14} dates to determine how long the ancestral Sheyenne River continued to flow, the sequence of events listed above implies that both time and water supply were sufficient to erode the soft bedrock and form the Sheyenne trench. When meltwater ceased flowing into the Sheyenne River from glacial Lake Souris, significant erosion in the Sheyenne trench was terminated and the ancestral Sheyenne River was reduced to the small, meandering stream it is today.

Bald Hill Creek.

Bald Hill Creek is a shallow, ephemeral stream which also occupies a rather large valley (Figure 5). This valley averages about one-fourth of a mile in width and ranges from about 30 to 60 feet in depth. Summer depths of water in Bald Hill Creek vary greatly, but an average in a fairly wet season might be 1.0 to 1.5 feet. The stream channel is noramlly about 12 to 15 feet in width. This creek has two branches, one which heads in Section 23, T. 148 N., R. 61 W., northwestern Griggs County, and one which heads near Stoney Lake in northeastern Foster County. The two branches merge in Section 23, T. 146 N., R. 61 W., and continue on a southeastward course into southern Griggs County. Although they are not formally designated as such, they will be called the east branch (Griggs County) and the west branch (Foster County) in this report. The east branch flows southward while the west branch first flows eastward into Griggs County and then southeastward to where the two streams join. Bluemle (1965, plate 1) has called the west branch a meltwater channel. Although he indicates that this

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Figure 9. Loam unit with overlying disturbed profile (NE¼, Sec. 23, T. 146 N., R. 59 W.). View looking northwest; brunton compass near center of photograph for scale.

channel heads near Juanita Lake in northeastern Foster County, he begins another channel north of Juanita Lake and extends it northward to the Sheyenne River meltwater channel. The east branch presently heads in Griggs County but its meltwater channel continues northward, joining the present Sheyenne River valley in the vicinity of Ottofy Lake, south-central Nelson County. A low drainage divide separates the present east branch from a small, ephemeral stream which flows northward into Red Willow Lake and thence into Nelson County.

Aronow (1963, Figure 3) indicates that the channel of the more prominent west branch was excavated when ice was standing at the McHenry-Cooperstown position (Figure 19, page 87). He mapped the Heimdal diversion channel as following the present course of the James River to its junction with the west branch and thence along the west branch instead of the James River channel (Figure 6). Because of Bluemle's more recent work, however, it appears that the Heimdal diversion channel followed the course of the present James River in its entirety and that the west branch was formed at a later date.

Both channels of this creek are incised in till deposits of the Kensal ground moraine and in outwash sediments from the McHenry and Cooperstown end moraines, the latter being time-equivalent to the Heimdal diversion channel. For these reasons, it is likely that the channels were formed when the ice had retreated to the North Viking-Luverne position.

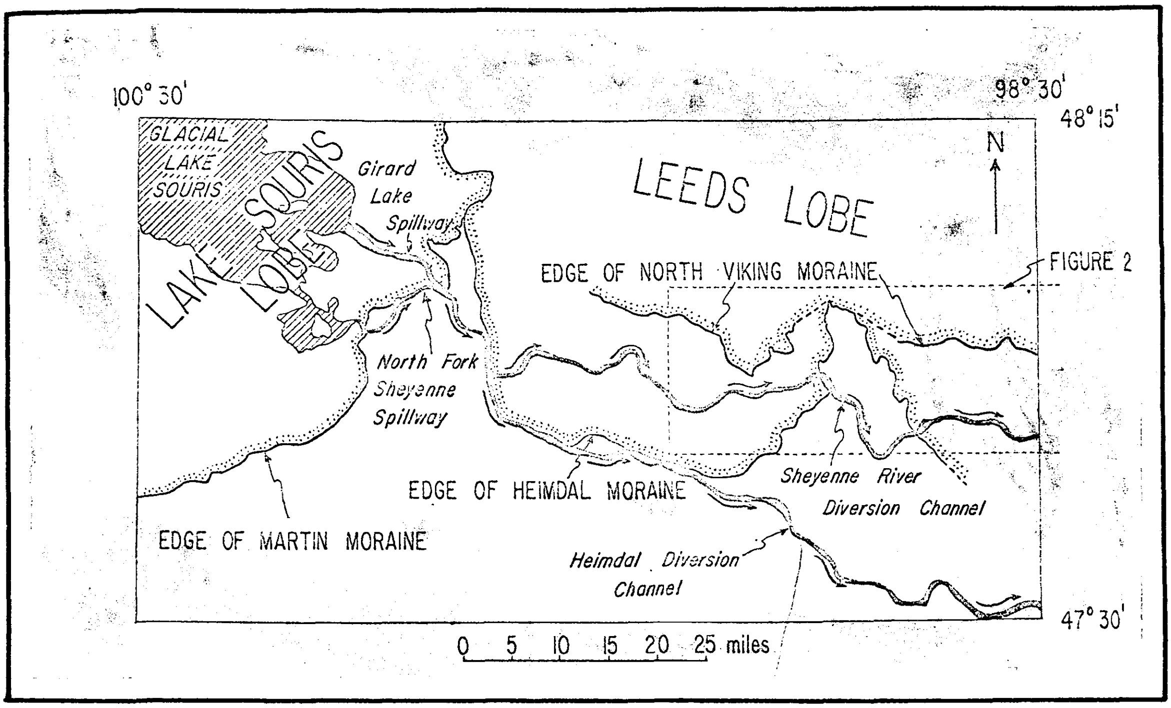


Figure 6. **Sketch map showing distal edges of moraines and spillways from glacial Lake Souris in east-central North Dakota (from Aronow, 1963, Figure 3).**

Before the ancestral Sheyenne River had become deeply entrenched, it is postulated that Souris Lake meltwater also found outlets southward through the two branches of the Bald Hill Creek. Evidence for such an interpretation includes: (1) Bluemle's (1965, plate 1) representation of a meltwater channel extending northward from the west branch to the Sheyenne valley, (2) both channels are incised in Kensal ground moraine and must have been carved since this sediment was deposited, (3) the incision of both channels in Heimdal-McHenry-Cooperstown outwash deposits which are younger than Aronow's (1963, Figure 3) diversion channel for the west branch indicates that the channels are also younger than the McHenry-Cooperstown outwash deposits, (4) streams presently occupying the channels are grossly underfit, indicating a much greater flow of water in the past. If the channels postdate the McHenry-Cooperstown deposits and if they are not the result of recent channel erosion, then they must have been carved between McHenry-Cooperstown time and the present. Also, since the channels are large, they probably are the result of meltwater erosion which occurred when ice was standing at, or in front of, the North Viking ice. Erosion in the Sheyenne trench, and/or a decrease in the amount of meltwater available, caused the creek channels to be captured by the ancestral Sheyenne River, and erosion in these valleys ceased.

Other streams

At least two of the minor stream valleys in the northern one-half of the study area were formed penecontemporaneous with the Bald Hill Creek meltwater channel. These valleys contain ephemeral streams which flow from west to east. The valleys are wide and shallow at their western extreme but become narrow and deeply entrenched as they approach the Sheyenne River valley. It is believed that these valleys were formed when water from the Bald Hill Creek meltwater channel overflowed its banks and found a temporary outlet to the east. Erosion in the valleys ceased when meltwater again became confined to the Bald Hill Creek channel.

The many other small stream channels throughout northern Griggs County were probably formed by the meltwater from a sheet of thin Cooperstown ice or numerous blocks of thin ice that were left behind by the retreating Leeds lobe.

Lakes

Only three scattered lakes in northern Griggs County contain water during extended droughts and can be truly called permanent. These lakes probably all intersect the ground water table and derive at least part of their water from available ground water supplies. The lakes are Hoot-e-too Lake, Red Willow Lake, and Lake Norway (Plates 1 and 2).

Although no depth figures are available on these three lakes, their topographic setting and permanent nature indicate that they are relatively deep. All of the lakes are situated in hilly areas where slopes in excess of seven degrees predominate. In addition to ground water seepage, the lakes derive a portion of their water from the surface run off which occurs on these slopes. Red Willow Lake is the only lake in northern Griggs County that has been commercially or privately exploited. A resort with a swimming beach, cabins and boat rentals, and a ballroom is situated on the southeast shore of the lake. Two riding stables and a small buffalo herd are also attractions of the area. In addition to these commercial ventures, many privately owned vacation cabins surround the lake.

Although Red Willow Lake and Hoot-e-too Lake may have resulted from the ponding of meltwater in an initial depression as the McHenry ice melted, most of the lakes in the area are kettles formed by the melting of buried blocks of glacial ice.

Many ephemeral lakes are also present in northern Griggs County. Lake Jessie, Sibley Lake and several other large lakes in the area must be classified as ephemeral because they are all very shallow and become dry after only short periods of drought. Of the lakes mentioned thus far, Sibley Lake is the only large body of water that is not situated in the loam unit of the Lostwood Formation (page 40). This lake is in the gravel unit (page 54) and has a bottom of recent lake clays. Although Sibley Lake is surrounded by hills which have greater than seven degree slopes, and derives some water from surface run off, it is probably a ground water table lake whose depth and area varies with the ground water table. It is the site of a large wild-life refuge and many migratory water fowl annually nest and feed in the lake. The lake varies from zero to one square mile in area but rarely exceeds 4.0 feet in depth.

Sibley Lake and several smaller lakes to the south are in an outwash deposit. These lakes are typical kettles. According to Flint (1957, page 140), most of the kettles in outwash, and all of the large ones, result from gradual upstream migration of the head of the outwash over a thin, irregular terminal zone of the glacier, which subsequently melts out. Because these lakes are all relatively large and shallow, they were probably formed in such a manner.

The line of lakes extending from Lake Norway southward to Lake Addie (south of Lake Jessie) are all situated on the eastern side of the Cooperstown end moraine. Although these lakes cover a considerable area during seasons with normal rainfall, they dry out during periods of drought. During a normal season, the depth of water in these lakes rarely exceeds five or six feet.

These lakes are either kettles formed by the melting of buried blocks of glacial ice, or they are ice marginal lakes formed by the ponding of water behind the Cooperstown end moraine as the ice withdrew.

The numerous, small lakes and sloughs east of the Cooperstown end moraine, as well as those south of Hoot-e-too Lake are kettles which were probably formed by slowly ablating ice when the thin glacier terminus became detached from the retreating Cooperstown ice.

Sloughs

Figures 12 and 16 (pages 52 and 65) illustrate the slough density in northern Griggs County. Differences in slough density reflect differences in lithologic units that underlie the sloughs. In the Luverne end moraine portion of the eastern plains, the slough density is about 14 per square mile (all figures are based upon a count of four square miles). This area is underlain by the loam unit of the Lostwood Formation where slopes average about 3° to 7° and where there is no integrated drainage. In contrast, the entire Sheyenne valley, which is bottomed with alluvial fill, contains only one slough in a four-square-mile area. In the southern part of the central rolling plains, where slopes average about 3° to 7°, the slough density is six per square mile. These sloughs have a considerable size range and several cover more than 10 acres (Figure 16, page 65). In the northwestern hills, the slough density is about 3 per square mile. With the exception of Sibley Lake and a few small lakes to the south, only one slough exists in an area of 45 to 50 square miles in the southwestern plains.

Because most of the sloughs discussed in the preceding paragraph overlie the loam unit (till) of the Lostwood Formation, many of them are probably kettles which have been formed in the same manner as the kettle lakes previously described. The central rolling plains are believed to have been covered by a detached block or blocks of Cooperstown ice. This would account for the slough and lake density in this area. Although some of the small sloughs present in the Luverne and moraine portion of the eastern plains may be kettles, it is believed that most of them were formed by ice-marginal ponding of glacial meltwater as the Luverne ice ablated in depressions formed by differential deposition of drift.

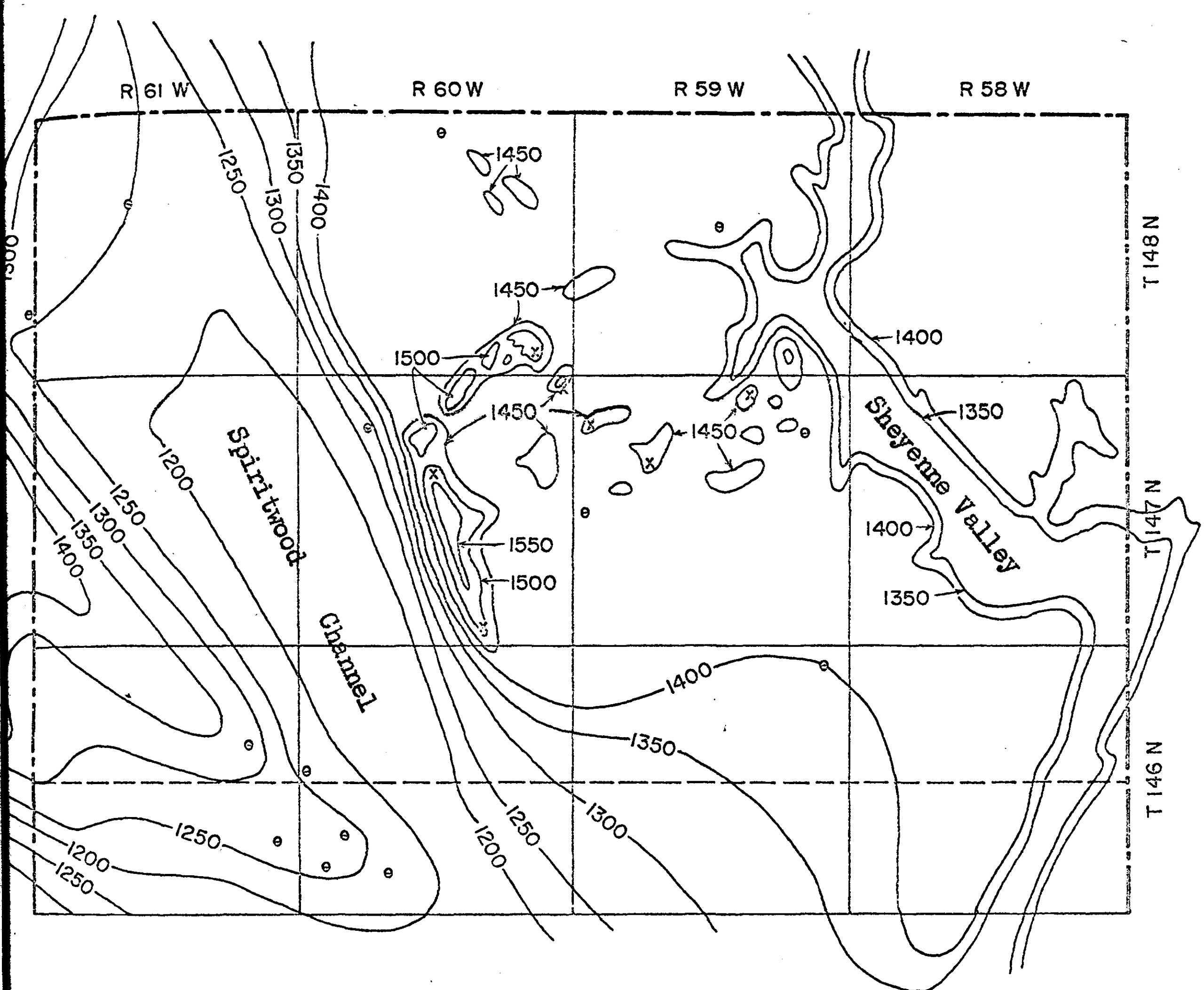
Ground Water

That the static water table is fairly close to the surface throughout much of the loam unit is evidenced by the many sloughs and undrained depressions that exist. In areas of sand and gravel, the ground water level is found at a greater depth. Ground water seeps are fairly common along the Sheyenne valley where the loam unit comes in contact with bedrock, but their yield is usually very low. During wet periods, water flows from those springs along much of the upper valley wall. Bald Hill Creek also contains a few springs but they do not appear to be important sources of water for the creek.

Data from several water wells in western Griggs County indicate that a large, buried stream valley exists under the mantle of glacial drift (Figure 7). These wells penetrate from two to four beds of till which are separated by thick units of outwash (Figure 8). The valley, which is indicated by the well data, presumably reaches a maximum depth of about

300 feet and varies in width from 5.5 to 8 miles. The upper margin of the valley is placed at the 1350-foot bedrock contour which appears to delineate the channel fairly well. This somewhat arbitrary upper margin was also used to determine the depth and width figures for the valley. Three tributary channels, ranging from 1.5 to 3 miles wide and from 50 to 150 feet deep, enter the valley from the north and west. One of these channels enters the northwestern part of the county from Nelson County, another enters from the northwest at the junction of Eddy and Foster Counties, and a third enters from the west through Foster County (Figure 7).

T.E. Kelly (1964) has given the name Spiritwood aquifer to a large, buried valley in Stutsman and Barnes Counties. It is believed that the valley in northern Griggs County is simply a northward extension of the same valley described by Kelly. In his report, Kelly discussed the problems involved in attempting to determine the direction of water flow in the valley in Stutsman and Barnes Counties. The bed is uneven and locally much ponding must have occurred during periods of low water when the valley was serving to channel surface run off and/or glacial meltwater. Recognizing that subsurface control is inadequate in northern Griggs County, it still seems certain that the ancestral stream occupying this valley flowed from north to south, throughout much of its existence, in this county. The general southerly gradient of the bedrock as well as the pattern of the tributary streams necessitates such a drainage direction. It is possible,



E X P L A N A T I O N

ө — Exact elevation from well data.
x — Bedrock outcrop (the Sheyenne River valley has bedrock exposed between 1350 and 1430 feet).
—1300— Contour line (interval is 50 feet).

Figure 7. Topographic map of the bedrock surface in northern Griggs County.

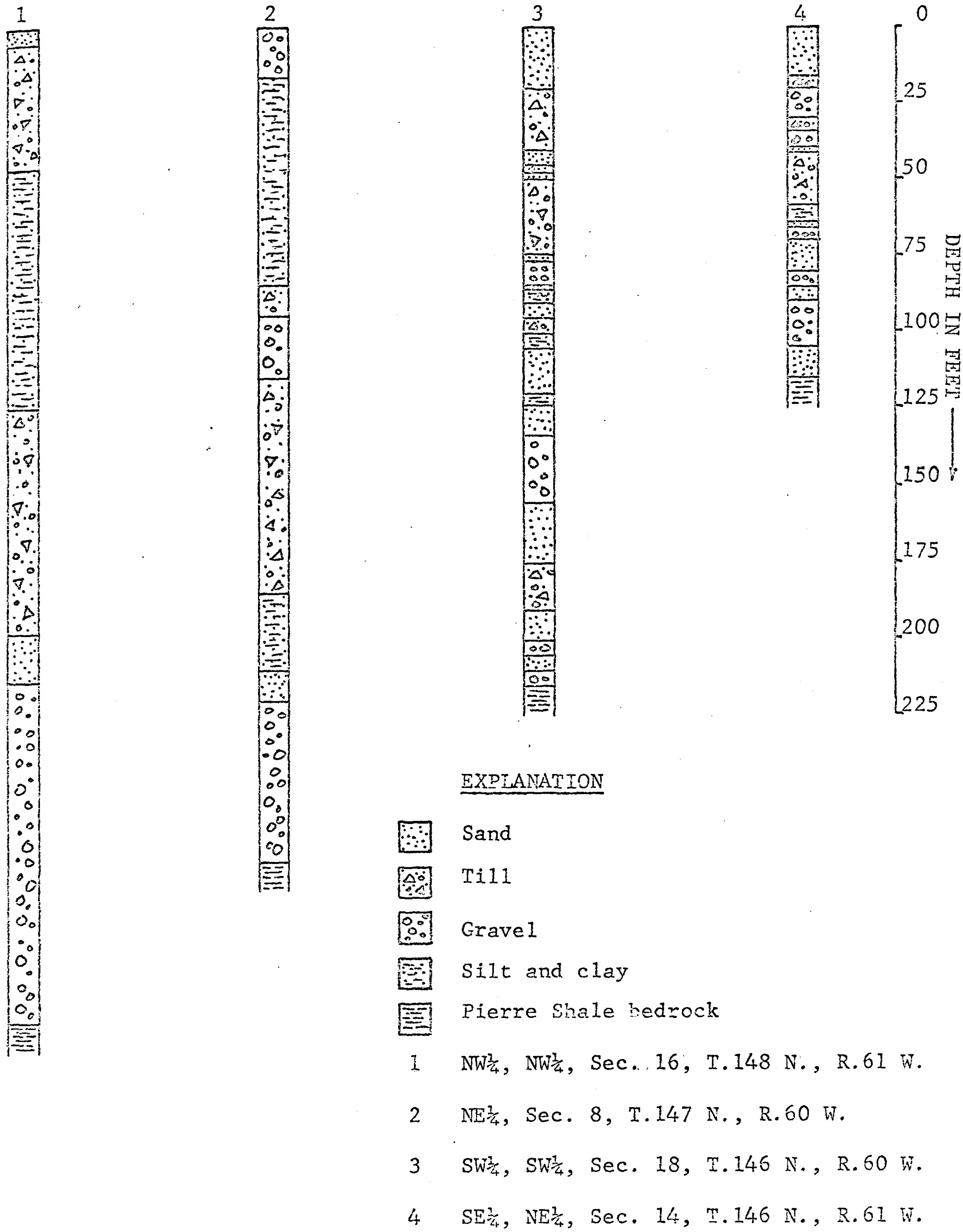


Figure 8. Selected water well logs from the Spiritwood Aquifer in western Griggs County.

however, that the principal channel also carried northward flowing water during a part of its history. Although no drilling or pumping tests have been initiated to determine the potential of this aquifer in Griggs County, the tests conducted in Stutsman and Barnes Counties indicate that it should yield large quantities of water. The bedrock contour map (Figure 7), however, indicates that northern Griggs County marks a north boundary for the Spiritwood aquifer. The tributary valley entering the major channel from Foster County has been called the Heimdal aquifer (Bluemle, 1965, page 63) and it is likely that the other two tributaries will also be given specific names in the future.

Kelly describes the sediments found in this valley as follows:

> "The gravel in the aquifer consists primarily of subangular to subrounded fragments of shale and limestone, although fragments of igneous and metamorphic rocks constitute as much as 20 percent of the total. The shale fragments were derived locally; however, the other rock fragments are typical of those in the Canadian Shield or lower Paleozoic sequence which borders the shield on the southwest. The sand grains range in size from very fine to very coarse and are angular to subangular. In areas of detailed test drilling, such as at sites A and B (Figure 2), the aquifer was found to differ lithologically both vertically and horizontally. In general, the lithologic characteristics of the sand and gravel indicate that these deposits were transported relatively short distances by large volumes of water. Silt and clay are only minor constituents of the aquifer and occur in thin, discontinuous beds" (Kelly, 1964, p. D165).

The youngest till which overlies the Spiritwood valley was deposited by the Leeds Lobe during McHenry-Cooperstown stand. The next youngest till, which is ablation till covered with McHenry-Cooperstown outwash, represents Kensal ground moraine deposited by the Leeds Lobe as it retreated across northern Griggs County. Although the age of the lower till deposits is unknown, it is likely that they are also late Wisconsin. But, the age or relative age of these tills does not accurately date the trench itself.

Huxel (1961) indicated that the Spiritwood valley in Stutsman and Barnes Counties was part of a preglacial drainage system containing a north-flowing stream. He also indicated that sediments in the valley were chiefly glacio-fluvial in origin. Studies in northern Griggs County, however, indicate that it probably contained a south-flowing stream throughout much of its existence. Huxel also indicated that an easterly trending, preglacial Heimdal valley extended into northern Griggs County through the bedrock channel subsequently mapped by Bluemle (1965, Plate 2). Although these channels have been called preglacial by Huxel (1961), Aranow (1963), and Flint (1955), no evidence exists to substantiate this supposition and it is just as likely that they are Pleistocene in age. Although the buried Spiritwood trench is considerably larger than that of the Sheyenne River, it is conceivable that it was also carved by glacial melt-water.

Lithostratigraphic Units

Pre-Pleistocene

Pierre Shale Formation:

This formation was named in 1862 by F.B. Meek and F. V. Hayden for exposures at old Fort Pierre, in either Stanley or Hughes County, South Dakota. It is the lower formation of the Montana Group, is overlain by Fox Hills beds, and overlies the Niobrara Formation. It is Upper Cretaceous in age and crops out in South Dakota, North Dakota, eastern Wyoming, eastern Montana, eastern Colorado, Nebraska, and western Minnesota. It consists of (descending): (1) dark-gray and bluish fossiliferous plastic clays; (2) middle zone, nearly barren of fossils; (3) lower fossiliferous zone; and (4) dark bed of very fine clay containing much carbonaceous matter, veins of gypsum, masses of sulphuret of iron, and numerous small fish scales.

The Pierre Shale Formation underlies the Pleistocene and recent sediments of northern Griggs County and has many good exposures. These exposures are identified by the standard "Kp" designation on the accompanying geologic map (Plate 1) and by the letter "G" on the lithologic map (Plate 2). A much generalized topographic map of the upper surface of this formation, included as Figure 2, locates most of the exposures in this area. As can be seen from these maps, the most extensive exposures exist on both sides of the Sheyenne valley. The ancestral Sheyenne River presumably carved this large canyon in the Pierre Shale Formation. Other outcrops of Pierre Shale are too small to be mapped but occur in the Binford Hills and at several of the rock-cored hills in the central rolling plains. Thickness of the formation in northern Griggs County is unknown but Bluemle (1965) reported thicknesses ranging from 250 to 1,100 feet in Foster and Eddy Counties, immediately west of Griggs County.

All exposures of the Pierre Shale in the study area are highly weathered. The shale is fissile and flakes along distinct but discontinuous, horizontal bedding planes. It is a light gray (N 7) to medium light gray (N 6), when dry and medium dark gray (N 4) to dark gray (N 3), when wet. Locally, bentonite lenses occur which give it a light gray color when wet and a popcorn-like surface when dry. These bentonite beds also contain yellowish-gray (5 Y 7/2) to grayish-orange (10 YR 7/4) limonite stains but do not constitute a very appreciable portion of the formation. Limonite stains are very common on fractures and small iron concretions occur throughout the formation. In this area, the shale is slightly fossiliferous.

The Pierre Shale Formation lies conformably on the Niobrara Formation and is unconformably overlain by Pleistocene or Recent sediments in this area.

Pleistocene

Introduction:

Primary depositional landforms have been used for many years as basic map units when describing Pleistocene and recent nonmarine sediments. In a time-stratigraphic, a rock-stratigraphic, or a geologic-climatic sense these units do not serve a very useful purpose. The units are not time equivalent, the lithologies vary considerably from place to place, and climatic fluctuations are ignored.

Frye and Willman (1960) recognized the limitations of each of these methods. They reasoned that units based upon the surface form they display were not time equivalent and could not be treated as time-stratigraphic units. They also felt that the lithologies involved in such sediments were too variable to apply normal rock-stratigraphic terminology. In like manner, they concluded that many of the various morainic units in Illinois and other north-central states were not sufficiently separated in time to allow geologic-climatic terminology to be applied. Working with the mass of published material that has been used to describe the glacial moraines in Illinois, Frye and Willman felt the need for a convenient unit which would recognize the variability of these units, and at the same time retain them for descriptive purposes. They proposed the recognition of a morphostratigraphic unit, giving it the following definition:

"a morphostratigraphic unit is defined as comprising a body of rock that is identified primarily from the surface form it displays; it may or may not be distinctive lithologically from contiguous units; it may or may not transgress time throughout its extent" (Frye & Willman, 1960, p. 112).

Although this terminology can be used to define a convenient unit and is readily applicable to Pleistocene deposits in North Dakota, it has genetic connotations which are based upon subjective interpretation. To avoid such connotations, the lithostratigraphic unit (defined in Article 4, Code of Stratigraphic Nomenclature, 1961) will be used to describe the Recent and Pleistocene sediments in northern Griggs County. It is felt that the sediments covering this area have sufficient lithologic similarities to warrant their recognition on lithologic character alone, without reference to topographic form.

Lostwood Formation

Definition

Pleistocene sediments in northern Griggs County are assigned to the Lostwood Formation. The name for this formation has been proposed by Clayton, 1964, (unpublished). The type area for the formation is near Lostwood Lake in northern Mountrail County, North Dakota.

Description

Clayton describes the lithology of the formation as follows:

> "The Lostwood Formation consists of three completely interfingering facies: a) slightly gravelly loam; grains generally rounded to subangular; clay fraction in large part calcareous montmorillonite; silt and sand fraction in large part quartz, feldspars, and shale fragments;

gravel fraction dominately fragments of limestone, dolomite, gray shale, light coarse-grained igneous and metamorphic rock types, basalt, and chert; usually no visible grain orientation; bedding generally lacking; generally grayish brown within several feet of the surface and dark gray deeper down. b) sand and gravel; dominately subrounded and rounded; grain mineralogy same as the gravelly loam facies, but shale content more variable; generally horizontally bedded with nearly horizontally-oriented grains; usually much better sorted than the gravelly loam facies; generally grayish brown and uncemented, though in places it is somewhat cemented or reddish. c) silt and clay; mineralogy same as silt and clay fraction of gravelly loam facies; frequently thinnly and evenly bedded; silt frequently brownish and clay frequently grayish near surface. The gravelly loam is most common of the three facies" (Clayton, 1964, unpublished manuscript).

Clayton describes the formation as lying unconformably on formations from Cretaceous to Pleistocene age and as being unconformably overlain by Recent sediments. It is distinguished from the overlying sediments by not being deposited at the present time. The formation ranges in thickness from a few feet west of the Missouri River, to a few hundred feet, east of the river. Although it is absent from the southwestern part of North Dakota, it occurs throughout portions of northern Minnesota, North Dakota, and Montana. The formation also extends into portions of south-central Canada. The exposed portions of the formation are Wisconsin in age, although some of the poorly-exposed lower portions may be pre-Wisconsin in age. The loam facies of the formation is largely glacial till, while the silt and clay facies is largely glacial lake sediments. The sand and gravel facies is largely glacial outwash and glacial-lake beach sediment.

Exposures

The Lostwood Formation has four surficial units in northern Griggs County. These are: (1) sand unit over loam unit, (2) sand unit, (3) gravel unit, and (4) loam unit. The first of these four units is actually a superposition of two of the basic units, but it is mappable and has lithologic characteristics which warrant its unit designation. The sand unit over loam unit is present only on the western portion of the central rolling plains while the loam unit is present throughout Griggs County. Although they occur at almost all locations in lesser amounts, the sand and gravel units are most important in the southwestern plains. The thickness of each of these units is highly variable and will be described when an individual unit is discussed.

Loam unit. This is the most widespread of the Lostwood Formation and, with the possible exceptions of the Sheyenne valley and the Binford Hills, covers all of northern Griggs County. Vertical exposures are common throughout northern Griggs County but are naturally more numerous and spectacular in the areas having steep slopes (Figure 7). The average lithologic and physical characteristics are of this unit are listed on Table 1.

Thickness of the unit varies considerably; on the upper banks of the Sheyenne valley, it is very thin, averaging about 2 to 3 feet. It is also thin in the central rolling plains where it overlies bedrock hills. Although it is typically only 4 to 5 feet thick, it may reach 6 to 8 feet on a few small, flat upland surfaces. It is also generally thicker in the area between these bedrock hills. The average thickness for the unit is about 8 feet.

Occurrences of gypsum characterize parts of the unit. In the extreme southwestern and west-central portions of the Southwestern plains, it occurs in lenses and pockets which, in some cases, account for 20 to 30 percent of a given loam sample.

This unit is the result of normal deposition by an actively moving glacier. It will be discussed in separate paragraphs treating such segment in the order in which it was deposited.

The Kensal ground moraine, which has two small exposures in the southwestern plains, was deposited at the front of the Kensal ice as it was retreating in a southeastwardly direction. According to Bluemle (1965), washboard moraines are abundant in Foster County and establish the direction of ice movement for this area.

The McHenry I end moraine, which is believed to be penecontemporaneous with the Cooperstown end moraine, was deposited by the retreating Leeds lobe during a temporary stillstand.

The drumlins which occur in this unit were probably formed by till deposition at the base of the ice as the Leeds lobe retreated across Griggs County toward the northeast. They are straight, narrow, and parallel ridges which,

Figure 9. Loam unit with overlying disturbed profile (NE$\frac{1}{4}$, Sec. 23, T. 146 N., R. 59 W.). View looking northwest; brunton compass near center of photograph for scale.

Table 1. Average lithologic and physical characteristics of the Loam unit in surficial deposits.

NAME: Loam unit

(1) Definition: Defined on basis of average grain size distribution.
(2) Distribution: Very widespread; covers much of study area.
(3) Thickness: Variable; 2 to 22 ft.; average about 8 ft.
(4) Sorting: Not sorted.
(5) Average grain size distribution: 9% gravel, 37% sand, 35% silt, 28% clay. Table 2 contains complete listing.
(6) Grain shape: Coarse fractions spheroid or disc-shaped.
(7) Grain roundness: Rounded to subangular.
(8) Grain mineralogy:
   (a) Clay and silt fraction: Quartz & clay minerals; chiefly montmorillonite.
   (b) Sand fraction: Chiefly quartz, feldspars and shale.
   (c) Gravel fraction: Chiefly carbonates, shale, igneous, and metamorphic.
(9) Grain orientation: Variable; pebbles generally aligned in direction of ice movement.
(10) Bedding: Generally lacking.
(11) Other primary structures: None.
(12) Cement: Lacking.
(13) Other secondary concentrations: Gypsum crystals prominent in some locations.
(14) Color: Mostly dark yellowish brown to grayish brown.
(15) Permeability: Usually quite low; largely determined by clay content.
(16) Induration: Hard to extremely hard when dry.
(17) Secondary structures: Iron concretions locally abundant.
(18) Stratigraphic position: Oldest of surficial Pleistocene deposits.
(19) Nature of contacts: Conformable except where overlying bedrock.
(20) Leaching of carbonates: Characteristically unleached and calcareous.
(21) Surface expression: Rolling (1° - 4°) to hilly (4° - 7°).
(22) Drainage: Largely unintegrated.
(23) Associated geomorphic landforms: End moraines, drumlins, ground moraine.

Table 2. Grain size analysis of the loam unit in northern Griggs County.

Station	Location	Clay	Silt	Sand	Gravel
		Percentages			
6A	Center, Sec. 16, T. 148 N., R. 61 W.	14.8	21.9	48.9	14.0
7A	NE corner, SE¼, Sec. 15, T. 148 N., R. 61 W.	8.6	24.5	55.2	11.7
8A	SE corner, Sec. 15, T. 148 N., R. 61 W.	11.1	46.2	39.5	3.1
12A	NE corner, SE¼, Sec. 16, T. 148 N., R. 61 W.	8.0	36.6	52.9	2.4
13	NE corner, Sec. 15, T. 146 N., R. 58 W.	15.7	27.5	47.5	9.2
22	SW corner, Sec. 9, T. 146 N., R. 58 W.	18.0	21.7	60.2	0.0
43	NW corner, Sec. 14, T. 146 N., R. 59 W.	16.5	35.6	31.9	16.0
76	NE corner, Sec. 22, T. 146 N., R. 60 W.	30.7	15.4	53.3	0.6
138B	SE corner, NE¼, Sec. 21, T. 146 N., R. 61 W.	29.5	32.0	29.4	9.0
138T	SE corner, NE¼, Sec. 21, T. 146 N., R. 61 W.	24.0	29.3	35.6	10.6
172	NW corner, Sec. 4, T. 146 N., R. 58 W.	23.7	26.3	34.5	15.5
184	NE corner, Sec. 1, T. 146 N., R. 59 W.	12.5	23.1	63.9	0.5
271	NE corner, Sec. 14, T. 147 N., R. 58 W.	20.7	30.7	41.7	6.7
291	SW corner, Sec. 33, T. 148 N., R. 58 W.	20.9	43.1	29.2	6.8
302	NE corner, Sec. 3, T. 147 N., R. 58 W.	18.6	24.6	39.8	17.0
308	NE corner, Sec. 1, T. 147 N., R. 58 W.	3.8	14.6	33.6	48.0
329	NE corner, Sec. 30, T. 147 N., R. 57 W. *	17.5	37.7	34.0	10.8
338A	NW corner, Sec. 30, T. 148 N., R. 58 W.	19.8	34.3	38.7	7.1
338B	NW corner, Sec. 30, T. 148 N., R. 58 W.	22.1	35.0	41.6	1.2
357	SW¼, Sec. 21, T. 148 N., R. 58 W.	17.0	28.1	42.6	12.2
360	NW corner, Sec. 18, T. 148 N., R. 57 W. *	26.4	35.4	37.0	2.1
388	NW corner, Sec. 14, T. 148 N., R. 58 W.	20.8	27.6	41.6	8.8
411	NE corner, SE¼, Sec. 5, T. 148 N., R. 58 W.	16.9	38.3	38.2	6.5
439	NW corner, NW¼, Sec. 2, T. 148 N., R. 58 W.	35.0	43.0	20.8	0.1
451	NW corner, Sec. 6, T. 148 N., R. 57 W.*	33.4	21.2	41.8	3.1
476	NW corner, Sec. 28, T. 147 N., R. 61 W.	29.9	58.8	10.0	1.1
579	SW corner, Sec. 7, T. 146 N., R. 60 W.	20.9	22.10	48.2	8.7
625	NW corner, Sec. 4, T. 146 N., R. 59 W.	29.5	51.6	18.5	0.4

Station	Location	Percentages Clay	Silt	Sand	Gravel
646	NW corner, Sec. 2, T. 146 N., R. 59 W.	17.1	38.0	33.9	10.9
659	NE corner, Sec. 25, T. 147 N., R. 60 W.	11.1	31.1	40.6	17.2
694	NE corner, SE$\frac{1}{4}$, Sec. 19, T. 147 N., R. 59 W.	15.3	46.7	37.7	0.3
700	NE corner, Sec. 23, T. 147 N., R. 60 W.	24.1	32.4	38.6	4.8
716	NE corner, Sec. 27, T. 147 N., R. 59 W.	26.1	25.7	37.8	10.4
722T	NW corner, Sec. 18, T. 147 N., R. 59 W.	17.0	29.8	47.7	5.5
728	SE corner, Sec. 36, T. 148 N., R. 60 W.	8.8	30.0	51.8	9.5
771	NE corner, Sec. 25, T. 148 N., R. 60 W.	14.4	18.1	50.2	17.2
780	NW corner, Sec. 28, T. 148 N., R. 59 W.	31.8	34.0	28.7	5.3
807	SW corner, Sec. 11, T. 148 N., R. 59 W.	26.0	20.4	30.6	22.9
838	NW corner, Sec. 18, T. 148 N., R. 59 W.	18.7	25.1	24.0	32.2
844	NE corner, Sec. 1, T. 148 N., R. 60 W.	45.7	28.8	19.5	6.0
870	NE corner, Sec. 3, T. 148 N., R. 59 W.	27.9	30.2	33.9	7.9
875	NW corner, Sec. 16, T. 148 N., R. 59 W.	16.9	24.0	48.2	10.9
904	NW corner, Sec. 28, T. 147 N., R. 60 W.	10.3	56.9	27.6	5.1
938	NE corner, Sec. 15, T. 147 N., R. 60 W.	11.4	41.8	33.7	13.0
960	NW corner, Sec. 4, T. 147 N., R. 60 W.	15.2	21.3	41.8	21.6
997	SW corner, Sec. 23, T. 148 N., R. 60 W.	46.4	40.0	13.1	0.4
1016	SW corner, Sec. 9, T. 148 N., R. 60 W.	31.4	21.5	40.4	6.7
1026	NW corner, Sec. 4, T. 148 N., R. 60 W.	64.2	27.9	7.7	0.1
1033	NW corner, Sec. 2, T. 148 N., R. 60 W.	31.3	53.2	15.3	0.1
1101	NE corner, Sec. 15, T. 147 N., R. 61 W.	8.0	31.2	60.4	0.4
1145	SE corner, Sec. 32, T. 148 N., R. 61 W.	23.5	26.6	35.3	14.5
1167	SW corner, Sec. 19, T. 148 N., R. 61 W.	29.8	21.0	34.8	14.3
1196	SW corner, Sec. 23, T. 148 N., R. 61 W.	15.7	70.2	12.6	1.4
1206	NE corner, NW$\frac{1}{4}$, Sec. 25, T. 148 N., R. 61 W.	18.7	32.4	38.9	10.0
1218	SE corner, Sec. 8, T. 148 N., R. 61 W.	11.3	24.6	41.4	22.6
1223	NW corner, Sec. 18, T. 148 N., R. 61 W.	14.7	29.4	41.4	14.4
1254	NW corner, Sec. 4, T. 148 N., R. 61 W.	25.1	26.2	37.5	11.2
1262	SW$\frac{1}{4}$, Sec. 36, T. 147 N., R. 67 W.**	20.2	33.9	39.6	6.3
1265	NW corner, Sec. 12, T. 146 N., R. 62 W.**	26.6	40.5	32.5	0.3

Station	Location	Percentages Clay	Silt	Sand	Gravel
1269	SW corner, NW$\frac{1}{4}$, Sec. 7, T. 146 N., R. 61 W.	35.9	43.2	19.3	1.6
1270	NE corner, Sec. 31, T. 146 N., R. 61 W.	9.5	12.8	77.9	0.0
1274	SW corner, Sec. 24, T. 146 N., R. 61 W.	28.3	34.2	30.6	6.9

* - Steele County
** - Foster County

in geometric configuration, closely resemble those described by Lemke (1958). Although the resemblence is striking, insufficient data have been compiled to conclude that their origin was the same. They are a minor portion of the sediment in northern Griggs County, and stratigraphically, are of little importance.

Although the origin of the numerous rock drumlins west of the Sheyenne valley is not fully understood, it is thought that they are the product of both erosion and deposition. Gravenor (1953) attributes the formation of most drumlins to his modified erosional theory. He states that: "since some drumlins are made of pre-existing materials, it is known that erosion can produce a drumlin. It is believed that halts or a slow advance during the forward movement of a glacier can give rise to a wide irregular surface of drift which would be shaped into drumlins by the advancing ice" (Gravenor, 1953, page 680). He does conclude, however, that where a bedrock or frozen till boss is present, the depositional theory is equally probable. Three of the rock drumlins in northern Griggs County were examined in detail. Two of these were observed to have cores of Cretaceous Pierre Shale on the stoss side. Although no bedrock core was exposed on the third drumlin, it had an extensive gravel deposit on its lee side which contained up to 60 percent Pierre Shale. Other rock drumlins that were less thoroughly examined were also observed to have very shaly gravel deposits on their lee sides. For these reasons it is proposed that most, if not all of the rock drumlins in the area have bedrock cores. The abnormally high amount of shale contained in till deposits on the lee side of these hills, as opposed to a very low shale content in till situated on the stoss sides, also suggests that the drumlins are rock cored. It is postulated that the advancing Leeds lobe moved up over a group of bedrock hills, eroding the soft Pierre Shale. Material obtained from the stoss side, the top, and the margins of these hills was mixed with sediment being carried by the glacier and subsequently deposited on the lee side of the hill. This description conforms to the crag-and-tail type of drumlin described by Flint (1959, page 66), but does not complete the explanation. It is believed that this phase of the drumlin formation served only to shape or mold them into their present form (Figure 10). The last phase in the formation occurred when the Cooperstown ice margin was retreating from the area. At this time, normal ground moraine (till) was deposited over the surface of these features, obliterating all traces of the rock core. Subsequent erosion of the till has exposed the gravel deposits and road cuts have exposed the bedrock core.

The Cooperstown end moraine was deposited by ice from the Leeds lobe which had retreated from the Kensal end moraine position. This ice may have stagnated after it overrode the Binford Hills, but it is more probable that it melted back still farther east.

Figure 10. Rock drumlin in the NW$\frac{1}{4}$, Sec. 2, T. 147 N., R. 58 W. Upper photograph looking northwest, lower photograph looking west.

Figure 11 depicts the probable series of events which led to the development of the Cooperstown end moraine. These steps are described in order. (1) Because the ice had become quite thin, the ridge or series of hills north of Lake Norway, Plate 1, caused it to split into two minor ice lobes. (2) Slight climatic fluctuations caused the terminus of the ice to fluctuate back and forth in the vicinity of the Binford Hills. On one of the advancing fluctuations the southern lobe moved southwestward until it reached the Binford Hills. (3) Upon reaching this ridge, the glacier moved upslope and produced linear ice thrust ridges (Figure 12, page 52). Although these ridges may be primary depositional features, they closely resemble ice-thrust ridges. The northern lobe also moved westward until it came in contact with the advancing McHenry I ice. (4) A portion of this lobe was diverted southward by the McHenry I ice until it was halted by the same ridge encountered by the southern lobe. As this ice moved upslope on the ridge, it produced arcuate ice thrust ridges. The ice ceased to fluctuate at this point and deposited till on top of the bedrock ridge.

The McHenry ground moraine was deposited when the ice melted back from the McHenry I to the McHenry II position (Plate 1). The absence of outwash sediments south of the McHenry II end moraine, however, implies that portions of the retreating ice may have been left behind on the ground moraine. Consequently, outwash derived from the McHenry II

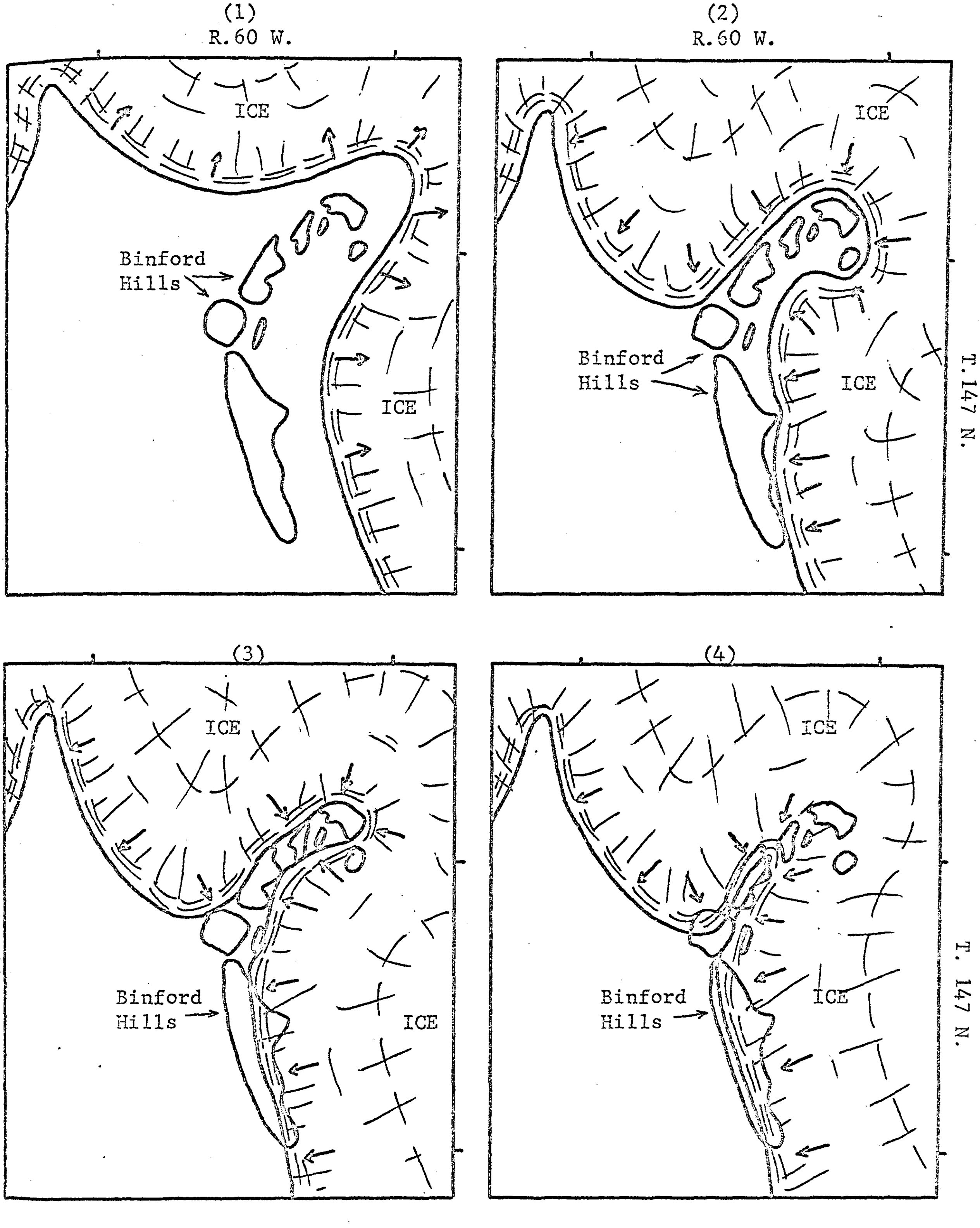


Figure 11. Phases in the formation of the Cooperstown end moraine and associated ice-thrust ridges.

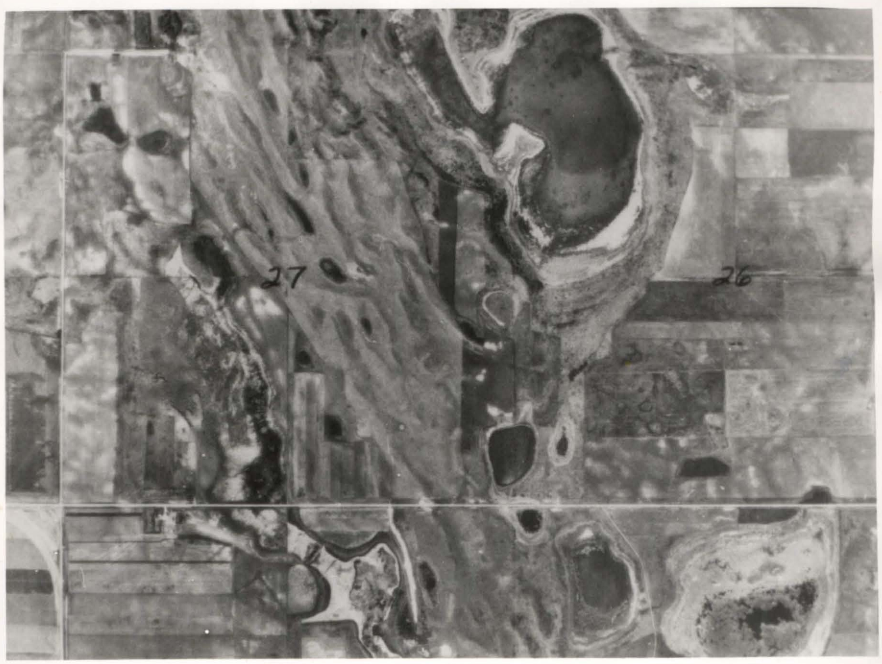


Figure 12. Southern portion of the Cooperstown end moraine showing linear ice thrust ridges and other features. Sections 22 and 27, T. 147 N., R. 60 W.

end moraine was deposited upon ice rather than upon a till surface. Melting of the ice caused most of the sand and gravel to be carried out of Griggs County. It is also possible that much of the outwash derived from the McHenry II end moraine, in this area, was carried out of the county and deposited elsewhere. Because the till found in the McHenry ground moraine is sandy, it may be concluded that outwash sands left behind were mixed with the till. This could have been accomplished by meltwater selectively carrying away the silt and clay portions of the till while leaving the sand behind.

Cooperstown ground moraine in the north-central part of the county was deposited as the Leeds lobe retreated from the Cooperstown end moraine. As the ice retreated from the southern portion of the central rolling plains, however, thin masses of ice were left behind. These masses later melted, producing a kame and esker complex in association with the ground moraine.

When the Leeds lobe melted back to the McHenry II position, the forward movement of the ice was equalled by the rate of melting and drift accumulated at its distal edge. After deposition of the McHenry-II end moraine, the ice retreated out of Griggs County.

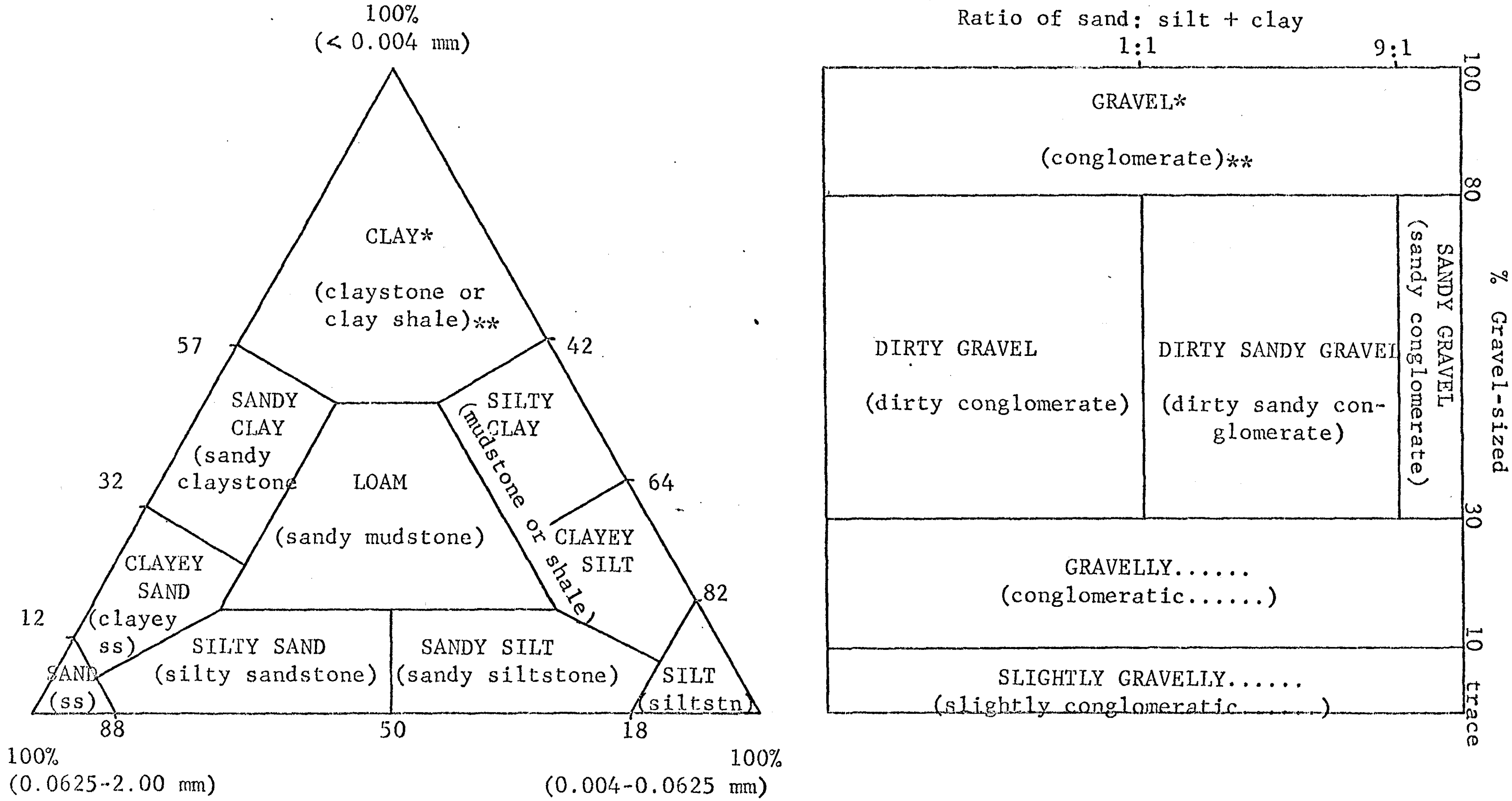
The retreat of the Cooperstown ice was temporarily halted in extreme eastern Griggs County, where it deposited the Luverne end moraine. The low relief and wide expanse of this end moraine suggests that the ice front fluctuated rather than stood at one location while the moraine was being deposited.

Gravel unit. This unit is widely distributed throughout northern Griggs County and contains coarse, clastic sediments with highly diverse lithologies. Although by definition this unit should contain 80 to 100 percent gravel (Figure 13), in this report it will also include sediments which have more sand than gravel. It is a part of the sand and gravel facies of the Lostwood Formation, and includes any sand and gravel deposit containing more than 5 percent gravel.

Although a general description of the lithologic and physical characteristics for this unit is given on Table 3, its variable composition and distribution necessitate further discussion.

Unlike the loam unit, the gravel unit is not continuous, but is distributed upon the loam unit and the Pierre Shale Formation in scattered localities. The most widespread exposure is in the southwestern plains (Plate 2) where it averages 12 to 15 feet in thickness. Although they are less widespread and not as thick, exposures in the northwestern hills and the eastern plains are very similar to the one found in the southwestern plains (Figure 14, page 58). In the Sheyenne valley the exposures cover less area, but are much thicker than the ones previously described. The largest of the Sheyenne valley exposures covers an area of about one square mile and is greater than 60 feet in

GRAIN-SIZE TERMINOLOGY (Wentworth scale)



* Nonlithified terms (upper case letters); can be dug with a shovel
** Lithified terms (lower case letters); cannot be dug with a shovel

Figure 13. Grain size terminology (from Clayton, 1965, p. 2)

thickness. Conical, linear, and sinuous members of the gravel unit occur throughout the central rolling plains as well as in the northwestern hills and the southwestern plains. Because these exposures of the gravel unit are often interbedded with the loam unit, actual thickness can only be estimated.

The gravel unit also differs in particle size distribution and in grain mineralogy. Although the contrasts are most striking in the physiographic areas mentioned above, there is also variation within a given area. In the southwestern plains, for example, the gravel ranges from coarse shaly gravel to fine quartz sand and gravel. Along the eastern edge of this area and particularly close to the Binford Hills, the unit is typified only by coarse, shaly gravel. Westward and southward from the Binford Hills, the gravel becomes progressively finer and lower in shale content.

Deposits of the gravel unit in the Sheyenne valley are also highly variable. In the Sheyenne valley, where the river makes an abrupt directional change, the unit is typically very sandy. The large exposure in Sections 13 and 24, T. 147 N., R. 58 W., contains about 95 percent fine to very fine sand and only about five percent gravel. This gravel generally occurs throughout the sand but some distinct lenses are also present. Farther north in the river valley, the unit contains more gravel, much of it being pea gravel and larger in size.

Table 3. Average lithologic and physical characteristics of the Gravel unit in surficial deposits.

NAME: Gravel unit

(1) Definition: Gravel or interbedded sand and gravel.
(2) Distribution: Widespread; largest exposure in southwest.
(3) Thickness: Variable; 6 to 8 foot average.
(4) Sorting: Usually well sorted.
(5) Grain size distribution: Variable; 90% gravel to 95% sand.
(6) Grain Shape: Disc and spheroid shapes predominate.
(7) Rounding: Dominately subrounded to rounded.
(8) Grain mineralogy:
  (a) Clay and silt fraction: Minor; not considered.
  (b) Sand fractions: Largely quartz, feldspar, and shale.
  (c) Gravel fraction: Variable; shale, carbonate, igneous, and metamorphic.
(9) Grain orientation: Discs are usually horizontally-oriented.
(10) Bedding: Generally horizontally bedded; fine to coarse.
(11) Other primary structures: Cross bedding is characteristic.
(12) Cement: Usually noncemented.
(13) Other secondary concentrations: Some gypsum in vugs.
(14) Color: Variable; determined by size distribution and grain mineralogy.
(15) Permeability: Usually very permeable.
(16) Induration: Variable; usually loose.
(17) Secondary structures: Iron concentrations abundant.
(18) Stratigraphic position: Overlies loam unit.
(19) Nature of contacts: Conformable.
(20) Leaching of carbonates: Variable with silt and clay content; usually leached.
(21) Surface expression: Flat $(< 1^{\circ})$ to hilly $(> 7^{\circ})$.
(22) Drainage: Integrated in Sheyenne valley & Bald Hill Creek areas.
(23) Associated geomorphic landforms: Outwash plains, eskers, kames primarily; some occurring in drumlins.

Figure 14. Gravel unit illustrating size distribution and bedding characteristics (SW¼, NW¼, Sec. 30, T. 148 N., R. 57 W., Steele County, North Dakota). Upper view looking southwest, lower view looking west; small shovel in lower photograph for scale.

The small, scattered occurrences of this unit in the central rolling plains, the southwestern plains and the northwestern hills display a fairly consistent size range, but differ radically in grain mineralogy. They typically contain more gravel than sand, and the gravel contains many large boulders at the surface. In the northwestern hills, the unit contains a high percentage of sand-sized particles and the gravel is primarily fine, individual pebbles rarely exceeding 15 mm in diameter.

Shape and rounding are variable and are intimately connected with the grain mineralogy. Where the gravel contains much Pierre Shale, individual pebbles occur as discs, but where little or no shale is encountered, they are more nearly spheroid.

At the western base of the Binford Hills, the gravel contains a high percentage of shale pebbles. The content varies from about 30 to 100 percent, the highest percentages being directly associated with the hills themselves. West and south of the Binford Hills, as well as in the eastern plains, igneous and sedimentary pebbles characterize the gravel.

Occurrences in the Sheyenne valley and the central rolling plains vary considerably and the shale content is determined by the stratigraphic position of a given deposit. Those very close to a source of Pierre Shale are naturally highest in shale. Table 4 shows the distribution of various pebble types at selected localities.

The origin of the sediments contained in this unit are variable and will be considered separately.

In the southwestern plains, the northwestern hills, and the eastern plains, this unit occurs as outwash deposits. The outwash was deposited by braided streams issuing from the terminus of an ablating ice sheet.

The geographic distribution of this unit in the southwestern plains implies that two major periods of outwash deposition have occurred (Plate 2). The unit occurs in two fan-shaped deposits which are separated by a band of outwash sand. The exposure extending farthest south was deposited while ice was standing at the McHenry-I and Cooperstown end moraine positions (Plate 1). At this time meltwater and outwash sediments were abundant and an extensive outwash deposit was formed. When the McHenry-I ice had melted back to the McHenry-II position and Cooperstown ice had retreated from its end moraine position, the less extensive, northerly outwash deposit was formed. This deposit is less extensive because Cooperstown ice was no longer supplying sediment to the area and a portion of the McHenry-II sediment was being diverted westward into Foster and Eddy Counties. Two additional retreats of the McHenry ice front caused similar situations to occur in the northwestern hills where end moraine (till) deposits are partially covered by outwash and collapsed outwash sediments. The collapsed outwash sediments, illustrated in Figure 15, resulted when sand and gravel were deposited upon thin ice

Table 4. Representative pebble composition of gravel unit in northern Griggs County. Data are based upon 1378 pebbles from nine localities which are representative of the various types of deposits found in the area. To be consistent, only pebbles between 0.156 mm and 0.312 mm were analysed.

Station	Location	Number of Pebbles		
		Shale	Carbonate	Other
909	NW Corner, Sec. 16, T. 147 N., R. 60 W.	76	40	25
917	SW Corner, Sec. 19, T. 147 N., R. 60 W.	100	13	22
493	SE Corner, Sec. 32, T. 147 N., R. 61 W.	2	72	80
481	SW Corner, Sec. 19, T. 147 N., R. 61 W.	32	30	41
133	NE Corner, Sec. 15, T. 147 N., R. 61 W.	74	48	58
105	SW Corner, Sec. 17, T. 146 N., R. 61 W.	12	80	52
1050*	SE Corner, Sec. 36, T. 149 N., R. 61 W.	65	38	42
970	SE Corner, Sec. 36, T. 148 N., R. 61 W.	37	41	36
1261	SW Corner, Sec. 24, T. 147 N., R. 58 W.	113	4	5
601	NE Corner, SE¼, Sec. 6, T. 146 N., R. 59 W.	146	3	1

*Nelson County

and let down as the ice melted.

Although the central rolling plains contain outwash sands adjacent to the Sheyenne valley, all of the gravel in the area occurs in kames and eskers. A kame is a mound-like hill of ice-contact stratified drift which may originate in either of two ways. It can either form by sediment being deposited in depressions in stagnant ice, or it can form by sediment being deposited as small deltas or fans against the ice. In the first type, it is common for a symmetrical mound to be formed when the ice melts, while in the second case, an irregular mound is usually formed. Although both types of kames occur in northern Griggs County, those with irregular outlines are most common. These features were formed in post-Cooperstown maximum time when the detached ice mass was slowly ablating.

Flint (1957, p. 152) defines an esker as a long, narrow, and commonly sinuous ice-contact ridge composed of stratified drift. Although he concedes that they may be formed in several ways, he feels that those formed in tunnels (less commonly in open channels) at the base of thin, ablating ice are most common. Several eskers in Griggs County fit Flint's definition exactly (Figure 16). In the southern portion of the central rolling plains, however, more eskers occur in swarms than as individual ridges and it is difficult, if not impossible, to single-out individual ridges. In all probability, these eskers have a more complicated history

Figure 15. Collapsed outwash sediments overlying the McHenry II end moraine in Sections 14 and 15, T. 148 N., R. 61 W.

and were formed by a combination of several factors. The large esker swarm in Sections 3, 9 and 10, T. 146 N., R. 59 W., has a definite braided pattern in Section 10, contains several tributary or distributory ridges, and is closely associated with a few small kames. Because this esker swarm is situated midway between the Cooperstown end moraine and the Sheyenne trench, it is likely that it was formed at the base of a thin, detached ice mass. Further evidence that this area contained the last remnant of Cooperstown ice is furnished by the eskers north and south of this esker swarm. Eskers immediately south of it drain to the south, while eskers north of it drain northeastward to the Sheyenne trench. Contemporaneous kame formation and later ice collapsing have complicated the feature, making it difficult to single-out individual ridges and/or mounds.

The last major exposure of this unit in the study area is in the terraces of the Sheyenne valley (Figure 17, page 66). These terraces occur at five distinct levels above the present flood plain and are the result of changes in the regimen of the ancestral Sheyenne River. These changes of regimen, from continuous eroding to alternating cutting and filling, may have been caused by any of several factors. The eroding stream may have lost competency and began depositing sediment because of a slight climatic fluctuation. (A cooler period would

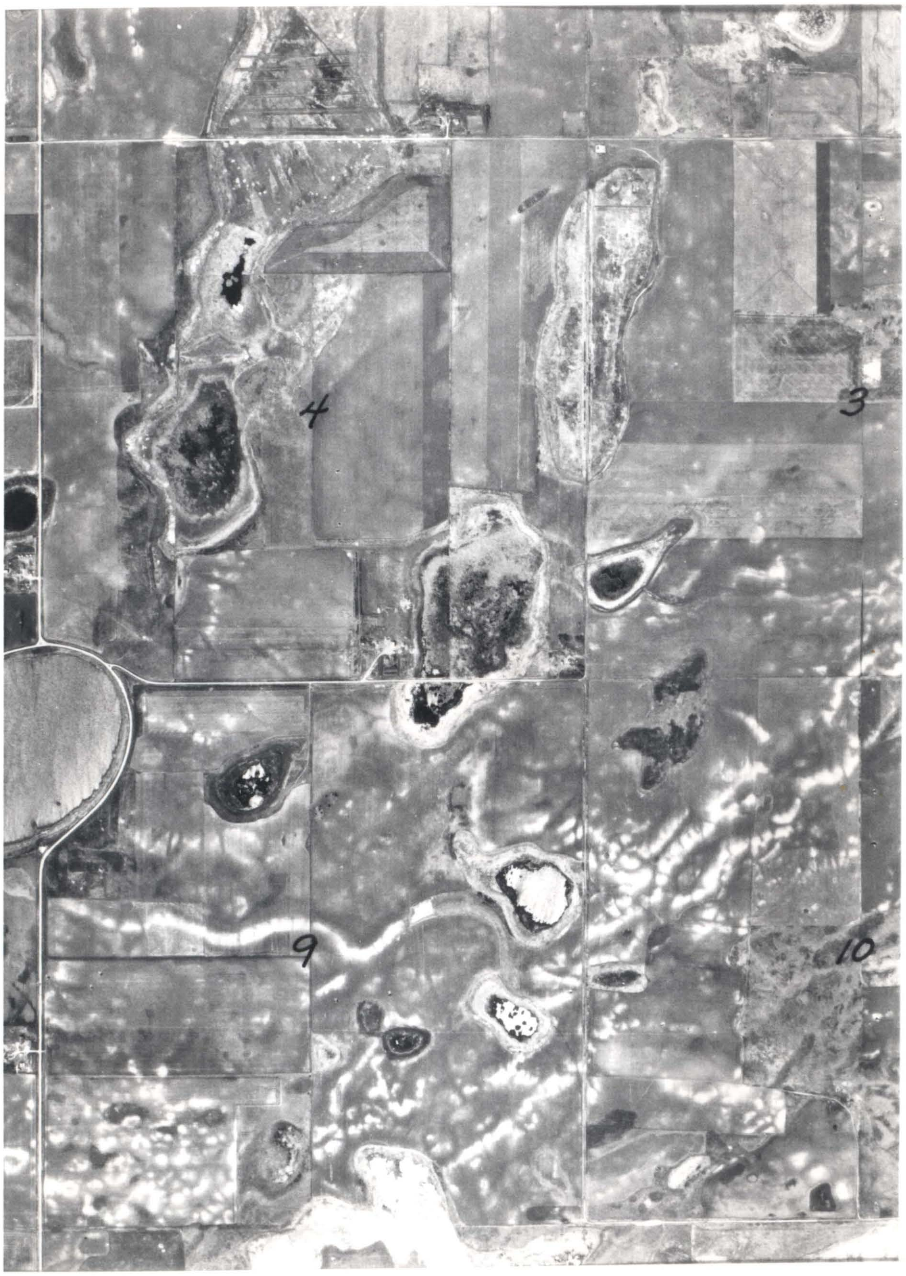
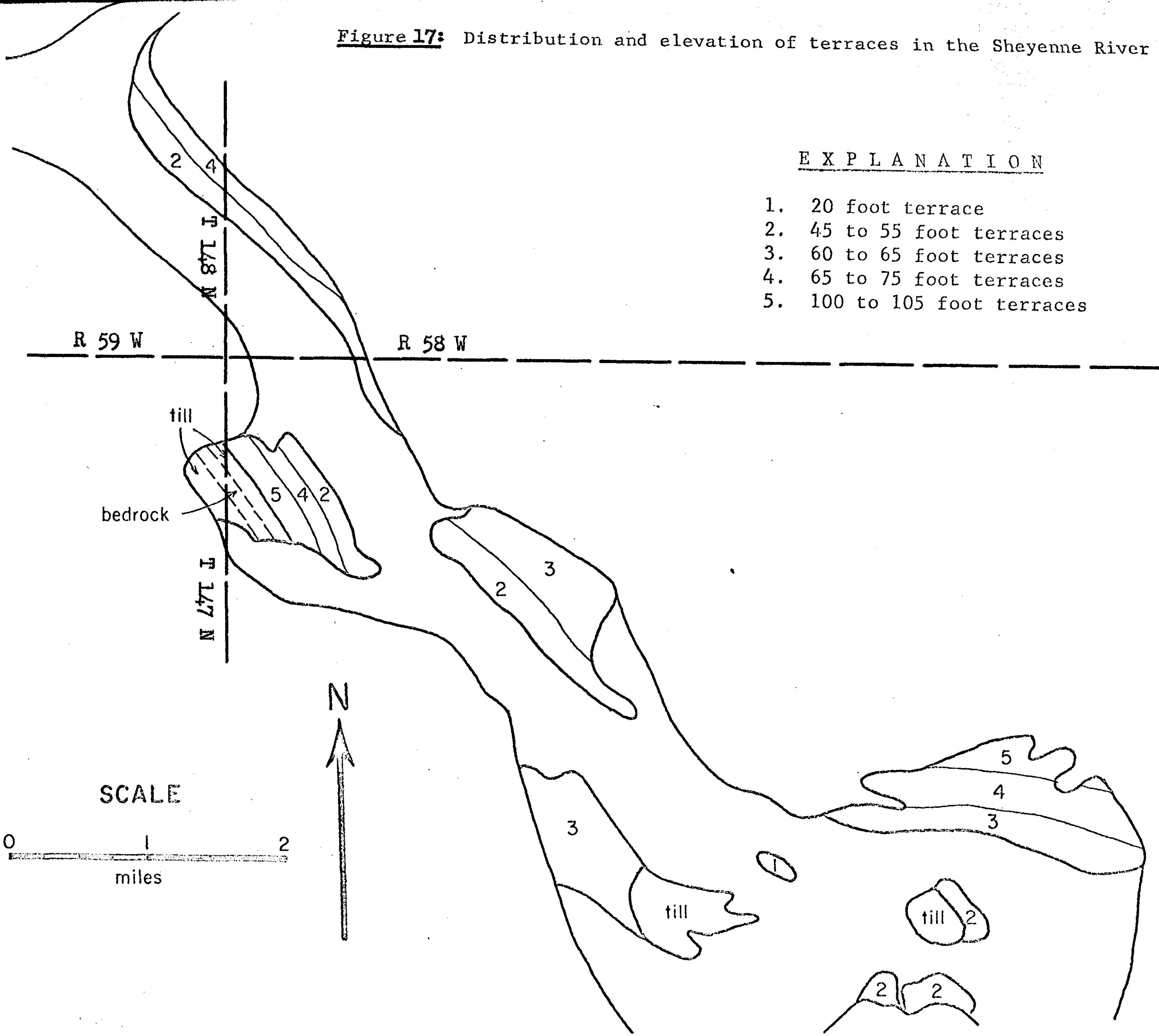


Figure 16. Individual esker and esker swarm in Sections 3, 4, 9, and 10, T. 146 N., R. 59 W.

Figure 17: Distribution and elevation of terraces in the Sheyenne River valley



would result in less melting of the ice mass and less meltwater available to the stream). The change may also have been the result of a rise in the base level of glacial Lake Aggassiz or the result of damming of the river below the terraces. Damming could have been caused by sediment deposition or by ice lodging in the channel. Aronow (1963) postulates that terraces in the Flora, Oberon, Tokio, and Pekin quadrangles were cut in valley fill by initial discharge through the North Fork of the Sheyenne spillway and that the trench was made by the more sustained discharge through the Girard Lake spillway (Figure 6, page 22). Since many of the terraces in the aforementioned quadrangles are strath or cut terraces, there is no apparent conflict in Aronow's supposition. Bluemle (1965) also indicates that at least two terrace levels in Eddy County contain only cut terraces. In northern Griggs County, however, no till or bedrock ledge was observed to be underlying any of the terraces; they all appear to be depositional, fill terraces. The large, multiple terrace in Sections 13 and 24, T. 147 N., R. 58 W., which is presently being mined, contains at least 60 feet of sand and gravel. Although it does not rule out the possibility that they are erosional features, the paired nature of the terraces also implies that they are till terraces. Although Aronow's idea may be valid, the Sheyenne trench could also have cut in in its entirety while ice was standing at the North Viking-Luverne position. It is believed that when the Girard Lake spillway was exposed, meltwater from glacial Lake Souris proceeded to excavate the Sheyenne trench. Initially, the flow of water down the Sheyenne diversion channel was small, but as the channel was deepened and the spillway was lowered further, the flow of water increased until it reached a bank-full stage. This large discharge of meltwater then completed the excavation of the Sheyenne trench and succeeded in lowering glacial Lake Souris sufficiently to decrease the flow of water again. Decreasing the amount of meltwater and/or changing the local base level, caused the stream to lose competence and the upper terraces were deposited. Individual fluctuations in stream discharge and/or changes in base level, caused the lower terraces to be formed in the same manner as the upper one. This suggestion does not rule out the possibility of cut terraces being present in Griggs County or at any point upstream from the study area. Cut and fill terraces can be formed contemporaneously at different locations within any stream channel.

Sand unit. With four exceptions, this unit is confined to the southwestern plains where it comprises about one-fourth of the total surface sediment. Although it can contain up to 5 percent gravel, the unit is hereby defined as one which is primarily sand. Most of the lithologic and physical properties of this unit are described on

Table 5. Bedding characteristics are shown on Figure 18, page 71. Grain mineralogy varies with the location of a particular deposit and is very similar to that described for the gravel unit.

The sediment belonging to this unit is outwash that was deposited by meltwater from the ablating terminus of a glacier. It was carried and deposited by a braided stream, the same stream in a given area, which carried and deposited the gravel unit. The sand is located farther from the source area than the gravel, because the transporting stream lost competency farther from its source and could no longer carry the gravel fraction.

That outwash that occurs in the eastern plains, was derived from the Luverne drift and deposited by meltwater from the Luverne ice (Figure 20, page 88).

The large deposit in the southwestern plains was derived from the Cooperstown and McHenry drifts (Figure 19, page 87). It was deposited at the same time and in the same manner as the gravel unit in the area.

<u>Sand unit over loam unit.</u> Although this unit is a combination of sand unit and the loam unit, it is extensive and merits individual attention and unit designation. It is a mappable unit which occurs exclusively along the western edge of the central rolling plains. The unit is distinct because of the homogeneous nature of the sand which overlies the loam. Other occurrences of the sand

Table 5. Average lithologic and physical characteristics of the sand unit in surficial deposits.

NAME: Sand unit

(1) Definition: Primarily sand; contains less than 5% gravel.
(2) Distribution: Most confined to west and southwest.
(3) Thickness: Variable; 10 to 12 foot average.
(4) Sorting: Well-sorted.
(5) Grain size distribution: Very coarse to very fine sand.
(6) Grain shape: Mostly spheroid; shale is disc shaped.
(7) Rounding: Dominately subrounded to rounded.
(8) Grain mineralogy:
  (a) Clay and silt fractions: Minor; not considered.
  (b) Sand fractions: Largely quartz, feldspar, and shale.
  (c) Gravel fraction: Same as for gravel unit.
(9) Grain orientation: Discs are usually horizontally-oriented.
(10) Bedding: Usually horizontally bedded, fine laminae (1-4 mm).
(11) Other primary structures: Cross bedding is very common.
(12) Cement: Usually noncemented.
(13) Other secondary concentrations: Some gypsum in vugs.
(14) Color: Variable; determined by size distribution and grain mineralogy.
(15) Permeability: Usually very high.
(16) Induration: Loose.
(17) Secondary structures: Iron concretions abundant.
(18) Stratigraphic position: Overlies loam unit.
(19) Nature of contacts: Conformable.
(20) Leaching of carbonates: Usually leached and non-calcareous.
(21) Surface expression: Flat ($< 1^{\circ}$) to hilly ($> 7^{\circ}$).
(22) Drainage: Integrated in Sheyenne valley and Bald Hill Creek areas.
(23) Associated geomorphic landforms: Primarily outwash plains, eskers, and kames.

Figure 18. Sand lens in the gravel unit (NE$\frac{1}{4}$, Sec. 7, T. 147 N., R. 58 W.).

unit are much more variable in size distribution, color and other lithologic characteristics. The sand is exposed over the entire area identified as "D/F" on the lithologic map. It varies in thickness from one to ten or more feet and has a well-developed soil profile. It is mapped wherever one or more feet of this sand overlies the loam. In the lithologic description, Table 6, only the sand portion of this unit is described. The loam portion of this unit is the same as that for the basic loam unit, previously described.

Although the sand in this unit is not found on the down-glacier side of the Cooperstown end moraine, it is considered to be an outwash deposit derived from the Cooperstown drift. Evidence to support this conclusion includes: (1) many small stream channels originate in the hilly area to the west and drain eastward to the Sheyenne valley, (2) several of the stream channels head at the northeast or east side of eastward sloping eskers and contain streams which drain into the Sheyenne River, (3) the sediment contains only fine and very fine sand which is not characteristic of other outwash deposits in northern Griggs County, (4) the maze of eskers, kames and kettles found in the area is characteristic of ablating, detached ice, (5) Luverne outwash on the east side of the Sheyenne valley is not as continuous or as extensive as this outwash deposit, (6) all of the kames and eskers in the area are boulder covered, indicating that the fines have been removed by running water. It is postulated that a large, thin block of ice became detached at the Sheyenne valley as the McHenry-Cooperstown ice retreated. Streams formed upon, within and/or beneath the ablating ice, carrying its meltwater away from the center of ice accumulation. These streams eroded material from the Cooperstown drift and deposited it peripheral to the wasting ice.

Recent Sediments

Black clay unit. This unit is confined almost exclusively to sloughs and undrained depressions and consists of grayish-black silty clay and clay. It is widely distributed throughout the area and is typically thin, probably averaging only three to four feet in thickness. Because this unit is confined to low areas with nonintegrated drainage, no vertical cuts are exposed. The 1965 field season was unusually wet in Griggs County and all of the sloughs contained water throughout the summer. For this reason, test augering, from which more precise sampling and depth data could be obtained, was nearly impossible. The lithologic and physical characteristics of this unit that were observed are listed in Table 7.

The clay and silt which comprise this sediment were deposited in the lakes and sloughs of northern Griggs County in post-glacial times. The sediment was derived

Table 6. Lithologic and physical characteristics of the Sand portion of the Sand unit over Loam unit.

NAME: Sand portion of Sand unit over Loam unit

(1) Definition: Exclusively fine to very fine sand.
(2) Distribution: Confined to western margin of Sheyenne valley.
(3) Thickness: Variable; from 1 to 10 or more feet.
(4) Sorting: Unsorted.
(5) Grain size distribution: Exclusively fine and very fine sand.
(6) Grain shape: Generally spheroidal.
(7) Rounding: Well-rounded.
(8) Grain mineralogy:
 (a) Clay and silt fraction: Very minor; not considered.
 (b) Sand fraction: Mostly quartz; some feldspar.
 (c) Gravel fraction: None.
(9) Grain orientation: None.
(10) Bedding: Characteristically poorly bedded.
(11) Other primary structures: None observed.
(12) Cement: Noncemented.
(13) Other secondary concentrations: Much organic matter present.
(14) Color: Dark yellow brown.
(15) Permeability: Very high.
(16) Induration: Loose.
(17) Secondary structures: None observed.
(18) Stratigraphic position: Overlies loam unit.
(19) Nature of contacts: Conformable below; unconformable above.
(20) Leaching of carbonates: Generally leached; calcareous in places.
(21) Surface expression: Undulating (1-4° slopes).
(22) Drainage: Unintegrated.
(23) Associated geomorphic landforms: Outwash plain.

from the hills and plains surrounding the sloughs by small, ephemeral streams and by sheetwash. Erosion of organic-rich topsoil from the surrounding area, has imparted the dark gray to black color to the sediment.

Interbedded sand-silt-clay unit. With the exception of the loam unit, this is the most widely distributed sediment in northern Griggs County. It is recent alluvial material which has been deposited in the streams and rivers of the county since deglaciation. The alluvial sediment consists of interbedded sand, silt and clay, although minor amounts of fine gravel is also present. The thickness of this unit is largely unknown but it is presumed to be about two to three feet thick in the small channel bottoms. In the Sheyenne valley, however, it is much thicker. Test holes near the town of Sheyenne, in Eddy County, penetrated 50 feet of alluvial fill near the center of the channel and about 15 feet near the margins. Although the 1965 field season was abnormally wet and this sediment was difficult to sample, the characteristics that were observed are listed in Table 8.

This sediment is composed of normal floodplain and channel deposits that have been accumulating in the rivers and streams since deglaciation.

The thickness of the unit in a given channel is directly proportional to the size of the channel and to the water available for transport and deposition. For this

Table 7. Average lithologic and physical characteristics of the Recent black clay unit

NAME: Black clay unit

(1) Definition: Organic rich dark gray to black Recent clays.
(2) Distribution: Confined to sloughs.
(3) Thickness: Variable: 1 to 3 ft. average.
(4) Sorting: Very well sorted.
(5) Grain size distribution: 64% clay, 28% silt, 9% very fine sand (average).
(6) Grain shape: Not observed.
(7) Rounding: Not observed.
(8) Grain mineralogy:
  (a) Clay fraction: Clay minerals; predominately calcareous montmorillonite.
  (b) Silt fraction: Mostly quartz, feldspar & shale.
  (c) Sand fraction: Same as silt fraction.
(9) Grain orientation: None observed.
(10) Bedding: Typically fine bedded (1-4 mm).
(11) Other primary structures: None observed.
(12) Cement: Poorly cemented to noncemented.
(13) Other secondary concentrations: Much organic matter present.
(14) Color: Silt portion brownish; clay portion grayish.
(15) Permeability: Very low permeability.
(16) Induration: Very hard to extremely hard when dry.
(17) Secondary structures: None observed.
(18) Stratigraphic position: Overlies sand, gravel, and loam units.
(19) Nature of contacts: Unconformable.
(20) Leaching of carbonates: Typically unleached and calcareous.
(21) Surface expression: Usually flat (< 1° slopes).
(22) Drainage: Integrated in part.
(23) Associated geomorphic landforms: Topographic lows; sloughs and undrained depressions.

reason, the Sheyenne River sediments are much thicker than those of the smaller streams. It has a larger source area from which to derive the sediments and more water with which to transport and deposit them.

The cross bedding and laminar structure characteristic of this unit is due to minor fluctuations in stream velocity and competency, which are governed by seasonal and daily climatic variations.

Table 8. Average lithologic and physical characteristics of the Recent interbedded sand-silt-clay unit.

NAME: Interbedded sand-silt-clay unit.

(1) Definition: Name implies definition (Recent).
(2) Distribution: Throughout area in stream & river channels.
(3) Thickness: Variable; thick in major rivers, thin elsewhere.
(4) Sorting: Very well sorted.
(5) Grain size distribution: 34% clay, 47% silt, 14% sand (average).
(6) Grain shape: Primarily spheroid.
(7) Roundness: Sand and silt well rounded.
(8) Grain mineralogy:
  (a) Clay fraction: Same as for black clay unit.
  (b) Silt fraction: Same as for black clay unit.
  (c) Sand fraction: Same as for black clay unit.
(9) Grain orientation: None observed.
(10) Bedding: Characteristically thin bedded (1-4 mm); thicker in Sheyenne valley.
(11) Other primary structures: None observed.
(12) Cement: Poorly cemented.
(13) Other secondary concentrations: Some organic material present.
(14) Color: Alternating bands of gray and brown.
(15) Permeability: Usually low; depends upon clay content.
(16) Induration: Hard to very hard when dry.
(17) Secondary structures: None observed.
(18) Stratigraphic position: Overlies loam, gravel, or sand units and Pierre Shale Formation.
(19) Nature of contacts: Unconformable.
(20) Leaching of carbonates: Typically unleached and calcareous.
(21) Surface expression: Flat to undulating.
(22) Drainage: Entirely integrated.
(23) Associated geomorphic landforms: Topographic lows; stream & river bottoms.

HISTORICAL GEOLOGY

Introduction

With the exception of the southwestern corner, all of North Dakota was glaciated during the Pleistocene epoch. Although its presence has been inferred, no drift of pre-Wisconsin age has been definitely identified in the state. The difficulty of differentiating the drift sheets and landforms on the basis of lithology, color, degree of weathering, and radiocarbon dating, complicates the Pleistocene chronology and makes dating tentative and subject to revision. As far as can be presently determined, only late Wisconsin drift is present in northern Griggs County.

Preglacial Setting

Although Paleozoic and Precambrian rocks underlie the glacial drift in southeastern North Dakota, throughout most of the state the drift rests upon easily eroded shales, siltstones and sandstones of Cretaceous and Tertiary age. Lemke, and others (1965, page 15), indicate that this bedrock surface was more dissected and hilly (resembling the present unglaciated portion of the state) than that of the present drift surface. This conclusion has important implications and explains why lobation of the ice sheets occurred. It is also important in northern Griggs County and is well-illustrated by the Binford Hills and the rock drumlins, which have cores of Cretaceous Pierre Shale. The advent of the Pleistocene epoch in North Dakota caused the drainage pattern to change. Flint (1949, p. 68, 1955, pl. 7), Lemke and Colton (1958, Fig. 2) and Lemke (1960, p. 108), indicated that all pre-glacial streams in North Dakota drained northward into Canada. At the present time, only those streams located east and north of the James River and north of the Missouri River drain into Canada.

Although rivers in Griggs County have always drained to the north, their pre-glacial and post-glacial channels have been altered considerably by glacial erosion and deposition. The buried Spiritwood channel and the present Sheyenne River are evidence of such changes.

Pre-Wisconsin Glaciation

The presence of pre-Wisconsin drift in North Dakota has not been proven. Several factors, however, suggest that ice may have advanced across the state in pre-Wisconsin time. Clayton (1962, p. 55) has described a well-consolidated till southeast of Bismarck which he believes to be pre-Wisconsin in age. Although they may have been ice-rafted, scattered granitic boulders, interpreted as being pre-Wisconsin in age, have been found several miles beyond the Wisconsin drift border in western North Dakota. Warren (1952, p. 1143-1156) and Flint (1955, p. 30-41) have described probable Illinoian drift in South Dakota.

It is reasonably certain that no pre-Wisconsin drift is present in Griggs County, but the presence of pre-Wisconsin ice is a distinct possibility. Although it is believed that the buried Spiritwood aquifer is Wisconsin in age, this does not rule out the possibility that it might be pre-Wisconsin.

Wisconsin Glaciations

Lemke, and others (1965), record six distinct and separate Wisconsin glacial advances in North Dakota, South Dakota and Montana. The first advance is dated as early Wisconsin and correlates to the pre-Farmdale period of Leighton (1960). Advances two through six are termed late Wisconsin and range upward from the "Iowan" to the Mankato Substage.

W.M. Laird (Lemke, et al., 1965, p. 23) however, recognizes only three distinct glacial advances in North Dakota. He states that all drifts younger than that of Advance 3 are recessional moraines from this main advance. Laird's interpretation will be used in this report, subdividing Advance 3 into four phases for convenience. Although these phases correspond to advances 3 through 6 of Lemke, and others (1965), they are defined to be recessional phases and not distinct and separate advances.

Advance 1

The drift deposited by this advance forms a northwest trending belt west of the Coteau du Missouri. It is distinguished by thin, patchy till deposits, scattered ice-contact stratified deposits, and erratic boulders. The granitic boulders and the orientation of the drift boulder indicate that the source area was to the northeast or east-northeast and that the ice advanced from this direction. The wide expanse of the terminal zone and the probable direction of movement indicate that ice from this advance crossed Griggs County.

Advance 2

Although the limits of this advance in North Dakota are not well defined, the Long Lake and Zeeland end moraines of Clayton (1962, p. 26-30) probably mark its terminus. Lemke, and others (1965, p. 22), place the limit at the outer margin of the Krem moraine in Mercer County, North Dakota. Because of the poorly defined limits of this advance, it is likely that the terminus of the ice was highly lobate and it can not be assumed with any certainty that it covered Griggs County. The age of this advance is uncertain.

Advance 3

Phase I

This phase is represented by prominent end moraines and drift which cover the entire Coteau du Missouri. According to Clayton (1962, p. 27), the prominence of this drift in northwestern North Dakota results from buried bedrock hills. Much of the drift surface is dead-ice moraine and is characterized by steep ridges, small looping, parallel ridges, nonintegrated drainage, sharp local relief, and numerous kettles. Although Lemke and Colton (1958, p. 47) assign a post-Tazewell-pre-Two Creeks age to this drift, Lemke, and others (1965, p. 23) feel that it should be assigned to the Cary stade of Wright and Ruhe.

Phase II

The terminus of this phase is marked by the Britton, Oakes, Kensal and Grace City end moraines in North Dakota. The orientation of constructional features, indicates that two lobes of ice were involved in this phase. It is believed that the lobation occurred when the late Wisconsin ice thinned and receded. Prior to this time, the thick ice had been little affected by topographic highs, but as it thinned, the highs impeded the flow and it was forced to flow around them. Bluemle (1965) has described this lobation as follows:

> "the two major late Wisconsinian ice lobes in the area were the James and Des Moines lobes. The James lobe flowed generally southeastward between the Missouri Coteau and the Red River Valley, while the Des Moines lobe flowed generally southward through the Red River Valley. The James lobe was forced to split at least twice in east central North Dakota as it thinned over bedrock highs.
>
> Details of the lobation of the late Wisconsin ice can be inferred from a study of the end moraines. The James lobe deposited the Buchanan end moraine in northern Stutsman County before the flow direction of the ice was substantially affected by the topographic highs mentioned above. Later, when the James ice thinned so that it could not override the Sully's Hill high in T. 152 N., R. 65 W., about 10 miles north of the Eddy County line, it flowed around both sides of it, leaving a band of stagnant ice on and to the south of the high in eastern Eddy County. The ice flowing around the west side of the high deposited the Grace City end moraine. The ice that flowed around the east side became indistinguishable from the Des Moines ice, and, for all practical purposes, became part of the Des Moines lobe. The Des Moines lobe then expanded westward and deposited the Kensal end moraine in the area that had been covered by James ice before it was diverted by the Sully's Hill high" (Bluemle, 1965, p. 57).

Although Bluemle used the term Des Moines lobe in his report, he feels that this designation is in error (verbal communication). By the time the Des Moines ice front retreated into North Dakota, it had lost its identity as the Des Moines lobe and could no longer be distinguished from the James lobe. Consequently, it should have been called the James lobe or a new term should have been proposed.

Dating of this and the younger phases of glaciation is difficult because of the unreliability and variability of the few radiocarbon dates that do exist.

As the James lobe receded from its position at the Kensal end moraine, it deposited a blanket of ground moraine in the southwestern portion of northern Griggs County. Contemporaneous with the retreat of this ice was the retreat of the James lobe from the Grace City end moraine position.

Phase III

When the retreating James ice became too thin to override the Turtle Mountains, it split into the Leeds and Souris River lobes. The Souris River lobe flowed south around the west side of the Turtle Mountains and deposited the Martin end moraine. The Leeds lobe, which was retreating from the Grace City end moraine position was temporarily halted and the Heimdal, McHenry-I and Cooperstown end moraines were deposited (Figure 19). Following the

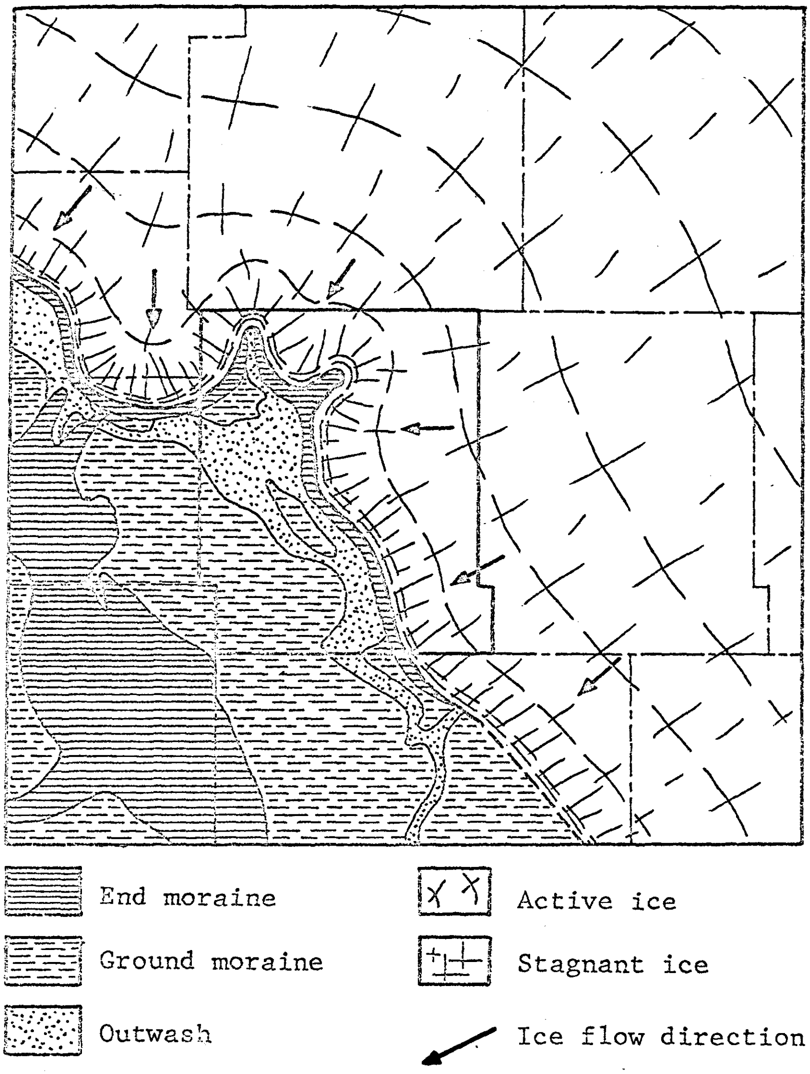


Figure 19. Advance 3, phase III of Pleistocene history. Formation of the McHenry and Cooperstown end moraines and associated outwash.

deposition of these end moraines, the ice again began melting back. The Leeds lobe retreated to the North Viking-Luverne end moraine position, depositing the North Viking and the Luverne end moraines (Figure 20). At this time, meltwater from glacial Lake Souris breached the Heimdal and McHenry end moraines and found an outlet down the Sheyenne River (Aronow, 1963, Figure 3).

Phase IV

After depositing the North Viking and Luverne end moraines, the Leeds lobe retreated up the Red River Valley and deposited the Edinburg end moraine. Although the age of this moraine is uncertain, it is believed to represent late Mankato time.

Post-glacial History

The topography of the area covered by drift of Advance I in North Dakota is very irregular and generally looks much like the adjacent nonglaciated areas. Drainage is well-integrated and only remnants of former glacial features exist. This fact indicates that either very little drift was originally deposited, or much time has elapsed since deglaciation of the area. In contrast, areas covered by Advances 2 and 3 have been very little modified since deglaciation. End moraines, drumlins, eskers, kames, and all other glacial features are well-preserved in Griggs County. Drainage is almost completely nonintegrated and

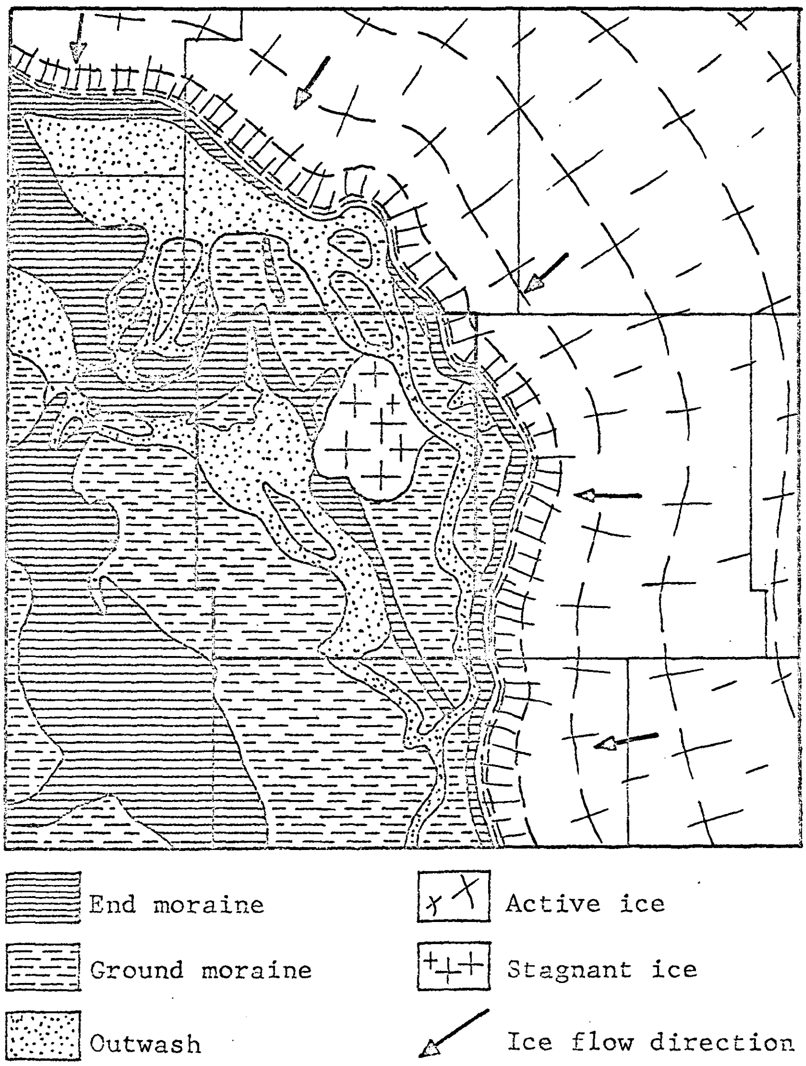


Figure 20. Advance 3, phase III of Pleistocene history. Formation of the North Viking and Luverne end moraines and associated outwash.

streams have deposited almost as much material as they have eroded.

SUMMARY AND CONCLUSIONS

The surface of Griggs County is mantled with four Pleistocene drift sheets which lie unconformably on Cretaceous Pierre Shale or on earlier Pleistocene drift. Two, or possibly three, of these earlier drift deposits underlie the surficial drift sheet. Because both the surficial and underlying drift sheets have similar lithologic and physical characteristics, and are late Wisconsin in age, they fulfill the requirements for a litho-stratigraphic unit and are collectively being considered for designation as part of the Pleistocene Lostwood Formation.

In this report, the McHenry end moraine has been divided into the McHenry-I and the McHenry-II end moraines. This division appears to be warranted for the following reasons: (1) each feature is a distinct, linear ridge, (2) the ridges are separated by ground moraine which is topographically lower than the ridges, (3) the geographic distribution of outwash south of the ridges indicates that two distinct periods of deposition have occurred.

The Cooperstown end moraine was produced by a flucuating ice front which moved up over a bedrock ridge, forming linear ice thrust ridges. It is discontinuous to the south of the ridge for either of two reasons. Either the ice had no sediment to deposit, or all of the sediment available for deposition was carried away from the ice front by glacial meltwater.

Because most of the eskers associated with the Cooperstown ground moraine were formed by northeasterly draining glacial streams, it appears likely that a block of Cooperstown ice became detached from the margin of the glacier as it retreated from the area. Streams issuing from the melting block of ice flowed in the direction of the retreating ice front, forming eskers and esker swarms. The outwash sand west of the Sheyenne valley was derived from the Cooperstown drift and deposited by the northeasterly flowing streams issuing from this detached block of ice.

Although many authors have dated the Sheyenne River channel as preglacial, no evidence was found in northern Griggs County to substantiate such a conclusion. It is probable that this channel was excavated by meltwater from glacial Lake Souris in late Wisconsin time.

As far as can be determined, the terraces of the Sheyenne River in northern Griggs County are all depositional, fill terraces. They were deposited by water from the ancestral Sheyenne River when downstream damming of the channel and/or a decrease in the amount of meltwater available caused the river to stop eroding and start depositing sediments.

The Spiritwood aquifer is a large, buried river channel that is filled with thick accumulations of outwash. It is confined to the western portion of northern Griggs County and appears to terminate near the northerly boundary of the county. The Spiritwood channel was probably excavated during the Pleistocene epoch, much like the Sheyenne River channel, and later filled with till and outwash deposits of late Wisconsin age. Although it is buried and has no surface expression, this aquifer has a depth in excess of 200 feet and a width that averages about 5 miles in northern Griggs County. It is a potential source of large quantities of water for agricultural and industrial purposes.

Although the writer has endeavored to describe and discuss the glacial geology, the Pleistocene stratigraphy, and the geologic history of northern Griggs County, several problems, which could not be resolved by surficial field methods, remain unsolved.

Of these unsolved problems, the dating of the Pleistocene sediments is the most obvious. More radiocarbon dates are necessary, throughout the glaciated portion of North Dakota, so that more precise dating of these sediments can be achieved. Other work that should be pursued in northern Griggs County includes: (1) definitive work on the extent and potential capacity of the buried Spiritwood aquifer, (2) deep drilling to determine the depth, characteristics, and mode of deposition of the sand and gravel deposits overlying the McHenry end moraine, (3) examination of the Sheyenne River terraces by deep drilling which may indicate potential reserves of sand and gravel as well as aid in the interpretation of their origin. Such a study might also aid in establishing whether the Sheyenne trench is pre-glacial, early Pleistocene, or late-Wisconsin in age, (4) determination of the depth and chemistry of the lakes and ground water, which would help to determine their source of water and natural potential, and (5) more definitive determination of the depth of till and outwash deposits. From such a study, a more detailed bedrock contour map could be drawn and the history of events that have occurred could be more precisely determined.

APPENDIX I

GRAIN SIZE ANALYSIS OF TILL

IN NORTHERN GRIGGS COUNTY, NORTH DAKOTA

A total of 63 till or supposed till samples were collected from the locations shown on Figure 21. They were analyzed by the N.D.G.S. Standard Procedures A-65, November, 1965. Gravel from each till sample was considered to be anything coarser than 2.0 mm in diameter. Sand included all material between 2.0 mm and 0.0625 mm in diameter. Silt covered the size range between 0.0625 and 0.0039 mm, while anything finer than 0.0039 mm was considered clay. The sand and gravel were dispersed in Kalgon solution, wet sieved, and weighed. Standard pipette analysis, as is outlined in the above-cited standard procedure, was used to determine the silt-clay break. A table listing the approximate percentages of sand, silt, clay, and gravel found in the samples is included on page 108. This table lists a "grand" average for the McHenry and Kensal drifts and divides them into two categories.

The youngest or stratigraphically highest drift is the Luverne. Because of the restricted exposure of this drift in the study area, only four samples were analyzed. All of these samples are from the Luverne end moraine. The drift is composed of approximately 37% sand, 33% silt, and 30% clay, exclusive of gravel. A total sample of this drift contains about 3.5% gravel and all samples are within the slightly gravelly sandy loam classification (Figure 13, page 55).

The Cooperstown-McHenry Drift is the next youngest in the area. For convenience, these drifts will be considered separately, beginning with the Cooperstown. Most of the samples from this drift were taken from ground moraine deposits which cover about one-half of northern Griggs County. In all, 39 till samples from 38 locations were analyzed from the Cooperstown Drift. The average composition of these samples is 42% sand, 34% silt, and 24% clay, exclusive of gravel. An average total sample of this drift contains 10.2% gravel. Of the 63 samples analyzed, 12 were within the gravelly sandy loam category and 13 were within the slightly gravelly sandy loam category. The other 14 samples ranged from loam, sand and gravel to sandy loam (no gravel), no one category occurring more than three times.

McHenry Drift is divided into till, collapsed outwash, and normal outwash deposits. Three of the samples were collected from end moraine, two from ground moraine, and five from the collapsed end moraine deposit. The till from the moraines has an average composition of 37% sand, 39% silt and 24% clay, exclusive of gravel. A total sample has an average of 11.2% gravel. Two of these samples were gravelly sandy loam, two were slightly gravelly sandy loam, and the third was slightly gravelly silt loam. The average composition of these samples places the unit in the gravelly sandy loam category. The outwash and collapsed outwash samples have an average composition of 54% sand, 34% silt, and 12% clay, exclusive of gravel, while a total sample has an average of 10.7% gravel. This composition average places the unit within the gravelly silty sand category. The composition also indicates that the McHenry Drift can be divided into two lithologically distinct units. Individually, three samples fall in the gravelly or slightly gravelly silty sand class, one falls in the slightly gravelly sandy silt class, and one falls in the gravelly sandy loam class. When these two units are combined, for an average composition of McHenry Drift, they contain 46% sand, 36% silt, and 18% clay, exclusive of gravel. The average percentage of gravel in a total sample is 11.0%. This combining of the samples would place the total composition into the gravelly sandy loam category and would give a false impression of the actual lithologies present.

The oldest drift in the study area is represented by ground moraine deposits of the Kensal Drift. This drift is also divided into two lithologic units. Initially, this division was based entirely upon geographic position. It was initiated to determine if a significant difference between the drift north of the major outwash area, which contains ablation till, and the drift south of the outwash existed. Although the difference is not as great as that found in the McHenry deposits, it is apparent and may warrant a division of units. Considered as one unit, the drift has a composition of 38% sand, 39% silt, and 23% clay, exclusive of gravel. It contains an average of 4.1% gravel in a total sample. This composition would place the drift in the slightly gravelly sandy loam category. Considered individually, the north unit has 40% sand, 34% silt, 26% clay, exclusive of gravel, and 2.2% gravel. This composition places it in the same category as the total north-south sample. The drift south of the outwash area contains 34% sand, 50% silt, 16% clay, exclusive of gravel, and 5.0% gravel. This places it on the border between the slightly gravelly sandy loam and the slightly gravelly sandy silt class. The difference between those two areas may be the result of the sandier ablation deposits to the north, the outwash itself, or a combination of the two factors. It is felt that the high percentage of silt in the south unit is the direct result of contamination by or mixing of these sediments with those of the outwash area.

Results of this study indicate that the lithologic variation within a given drift sheet is as great, or greater, than the variation between different drift sheets. For this reason, it is concluded that lithologic characteristics cannot be used to differientate the drift sheets in northern Griggs County. It is also concluded that, on the basis of lithology and other physical characteristics, the various drift sheets represented in northern Griggs County can and should be given member status in the proposed Lostwood Formation.

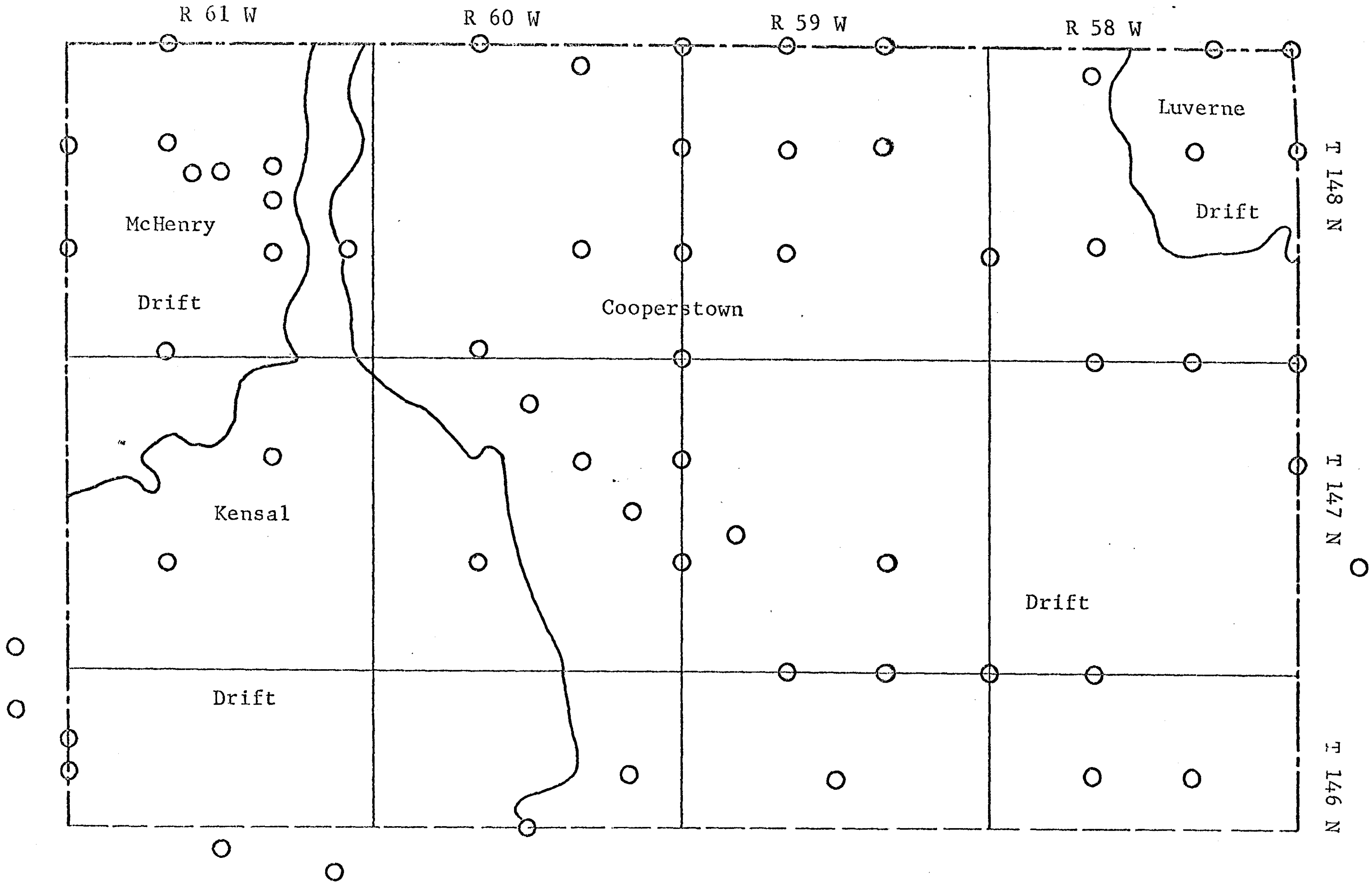


Figure 21. Loam unit sample sites in northern Griggs County.

Kensal Drift (10 samples)

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

	Larger subsample (gm)					Smaller subsample (gm)					Entire sample (%)				
Column	AA	A	B	C	D	E	F	H	J	K	L	M	N	P	
Paragraph	5	6	6a	6b	6c	12	9a	9c	9d	9e	10a	10b	10c	10d	
Material	total moist	total dry	gravel	sand	silt + clay	total moist	contents of beaker	sediment in beaker	clay	silt	gravel	sand	silt	clay	
Calculation					A-B-C	15(AA)/D		F-.08	50H	15.0-J	100B/A	100C/A	100DK/15A	100DJ/15A	
138B (vwi)	161.3	157.2	14.27	46.19	96.73	24.34	.224	.144	7.20	7.80	9.05	29.35	31.96	29.50	99.86 %
138T (vpi)	183.4	179.7	19.08	63.82	95.80	27.90	.215	.135	6.75	8.25	10.62	35.60	29.33	23.97	99.52 %
1262 (wi)	161.1	157.1	9.82	62.19	85.08	27.70	.192	.112	5.60	9.40	6.26	39.60	33.90	20.20	99.96 %
1265 (vwi)	176.2	170.4	0.48	55.46	114.5	22.32	.199	.119	5.95	9.05	0.28	32.50	40.50	26.62	99.90 %
1269 (wi)	152.5	147.7	2.39	28.46	116.8	18.95	.216	.136	6.80	8.20	1.61	19.30	43.20	35.87	99.98 %
1270 (fwi)	189.2	189.0	0.00	147.4	41.65	67.79	.206	.126	6.30	8.70	0.00	77.90	12.78	9.50	99.98 %
1274 (pi)	158.6	149.9	10.30	45.93	93.64	24.00	.216	.136	6.80	8.20	6.87	30.64	34.16	28.32	99.99%
476 (pi)	130.2	125.3	1.36	12.57	111.4	16.86	.181	.101	5.05	9.95	1.08	10.00	58.83	29.90	99.81 %
904 (pi)	164.7	162.3	8.32	44.82	109.1	22.30	.126	.050	2.30	12.70	5.13	27.60	56.90	10.30	99.93 %
1101 (vpi)	192.5	190.2	0.79	114.8	74.56	38.30	.141	.061	3.05	11.95	0.44	60.40	31.20	7.96	100.00 %

McHenry Drift (10 samples)

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

Column	Paragraph	Material	Calculation	1145 (fwi)	1167 (pi)	1196 (fwi)	1218 (fwi)	1223 (pi)	1254 (fwi)	6A (pi)	7A (vpi)	8A (Pi)	12A (pi)
AA	5	total moist		167.5	168.6	153.1	203.1	178.9	176.0	140.6	206.2	162.4	182.3
A	6	total dry		165.2	166.4	150.8	200.9	176.0	174.7	137.6	203.9	160.9	180.7
B	6a	gravel		24.00	23.82	2.17	45.32	25.58	19.51	19.23	23.79	5.00	4.28
C	6b	sand		58.38	57.91	19.07	83.23	73.12	65.53	67.32	112.6	63.60	95.64
D	6c	silt + clay	A-B-C	82.83	84.70	129.56	72.35	78.11	89.65	50.62	67.63	92.34	80.78
E	12	total moist	15(AA)/D	30.35	29.90	17.72	42.10	34.37	29.48	41.63	45.70	26.40	33.87
F	9a	contents of beaker		.221	.256	.135	.175	.180	.227	.201	.158	.136	.134
H	9c	sediment in beaker	F-.08	.141	.176	.055	.095	.100	.147	.121	.078	.058	.054
J	9d	clay	50H	7.05	8.80	2.75	4.75	5.00	7.35	6.05	3.90	2.90	2.70
K	9e	silt	15.0-J	7.95	6.20	12.25	10.25	10.00	7.65	8.95	11.10	12.10	12.30
L	10a	gravel	100B/A	14.53	14.31	1.44	22.57	14.45	11.16	13.98	11.67	3.11	2.37
M	10b	sand	100C/A	35.30	34.80	12.65	41.41	41.37	37.48	48.90	55.20	39.50	52.92
N	10c	silt	100DK/15A	26.58	21.04	70.15	24.60	29.45	26.18	21.94	24.51	46.24	36.60
P	10d	clay	100DJ/15A	23.53	29.85	15.71	11.28	14.72	25.14	14.84	8.62	11.08	8.04
				99.94 %	100.00 %	99.95 %	99.86 %	99.99 %	99.96 %	99.66 %	100.00 %	99.90 %	99.93 %

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

Column	AA	A	B	C	D	E	F	H	J	K	L	M	N	P	
Paragraph	5	6	6a	6b	6c	12	9a	9c	9d	9e	10a	10b	10c	10d	
Material	total moist	total dry	gravel	sand	silt + clay	total moist	contents of beaker	sediment in beaker	clay	silt	gravel	sand	silt	clay	
Calculation					A-B-C	15(AA)/D		F-.08	50H	15.0-J	100B/A	100C/A	100DK/15A	100DJ/15A	
13 (vwi)	158.0	156.0	14.39	74.09	67.52	30.60	.189	.109	5.45	9.55	9.22	47.50	27.52	15.72	99.96 %
22 (vwi)	169.4	167.1	0.01	100.6	66.40	38.28	.216	.136	6.80	8.20	0.01	60.20	21.72	18.00	99.92 %
43 (fwi)	127.5	124.1	19.81	39.51	64.78	29.54	.175	.095	4.75	10.25	15.96	31.87	35.63	16.52	99.98 %
76 (vwi)	178.6	177.1	1.04	94.44	81.60	32.82	.280	.200	10.00	5.00	0.59	53.30	15.35	30.70	99.94 %
172 (vwi)	179.6	176.8	27.44	60.91	88.45	30.50	.222	.142	7.10	7.90	15.50	34.46	26.34	23.70	100.00 %
184 (pi)	171.6	169.5	0.78	108.3	60.38	42.64	.185	.105	5.25	9.75	0.46	63.86	23.13	12.46	99.91 %
271 (pi)	144.6	141.9	9.75	59.10	73.01	29.70	.201	.121	6.05	8.95	6.74	41.66	30.70	20.73	99.83 %
291 (wi)	153.4	151.0	10.21	44.09	96.70	23.80	.178	.098	4.90	10.10	6.76	29.20	43.10	20.90	99.96 %
302 (fwi)	135.3	132.7	22.61	52.75	57.34	35.40	.209	.129	6.45	8.55	17.04	39.75	24.62	18.57	99.98 %
308 (vpi)	118.8	116.5	55.88	39.11	21.51	82.85	.142	.062	3.10	11.90	47.96	33.58	14.65	3.81	100.00 %
329 (pi)	139.5	136.4	14.77	46.33	75.30	27.80	.175	.095	4.75	10.25	10.84	34.00	37.70	17.46	100.00 %
338A (vwi)	168.4	165.6	11.81	64.09	89.70	28.20	.190	.110	5.50	9.50	7.12	38.69	34.28	19.84	99.93 %
338B (vwi)	175.5	171.1	2.00	71.25	97.81	26.92	.196	.116	5.80	9.20	1.17	41.61	35.00	22.10	99.88 %
357 (fwi)	151.3	149.0	18.13	63.55	67.32	33.74	.193	.113	5.65	9.35	12.17	42.62	28.14	17.00	99.93 %
411 (pi)	147.1	143.5	9.37	54.86	79.27	29.70	.172	.092	4.60	10.40	6.52	38.22	38.28	16.94	99.96 %
579 (pi)	152.6	150.3	13.12	72.55	64.66	35.42	.226	.146	7.30	7.70	8.72	48.25	22.10	20.92	99.99 %
625 (wi)	148.0	144.4	0.62	26.67	117.2	18.95	.189	.109	5.45	9.55	0.43	18.46	51.64	29.46	99.99 %

Cooperstown Drift (page 2)

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

Column	AA	A	B	C	D	E	F	H	J	K	L	M	N	P	
	Larger subsample (gm)					Smaller subsample (gm)					Entire sample (%)				
Paragraph	5	6	6a	6b	6c	12	9a	9c	9d	9e	10a	10b	10c	10d	
Material	total moist	total dry	gravel	sand	silt + clay	total moist	contents of beaker	sediment in beaker	clay	silt	gravel	sand	silt	clay	
Calculation					A-B-C	15(AA)/D		F-.08	50H	15.0-J	100B/A	100C/A	100DK/15A	100DJ/15A	
646 (fwi)	157.3	154.3	16.84	52.35	85.11	27.75	.173	.093	4.65	10.35	10.91	33.92	38.02	17.09	99.94 %
659 (pi)	135.9	132.3	23.15	53.29	55.86	36.50	.159	.079	3.95	11.05	17.20	40.58	31.10	11.12	100.00 %
694 (fwi)	134.7	133.5	0.38	50.31	82.85	24.40	.154	.074	3.70	11.30	0.28	37.70	46.72	15.30	100.00 %
700 (pi)	146.6	143.7	6.88	55.49	81.33	27.08	.208	.128	6.40	8.60	4.78	38.60	32.42	24.12	99.92 %
716 (fwi)	161.3	159.1	16.50	60.15	82.45	29.38	.231	.151	7.55	7.45	10.38	37.80	25.73	26.09	100.00 %
722T (pi)	138.6	136.9	7.52	65.38	63.99	32.50	.189	.109	5.45	9.55	5.49	47.73	29.77	16.97	99.96 %
728 (vpi)	178.3	176.4	16.71	91.39	68.27	39.20	.148	.068	3.40	11.60	9.48	51.80	29.95	8.77	100.00 %
771 (vpi)	129.8	127.0	21.89	63.80	41.32	47.20	.213	.133	6.65	8.35	17.23	50.20	18.10	14.42	99.95 %
780 (wi)	150.6	147.8	7.87	42.52	97.45	23.20	.225	.145	7.25	7.75	5.32	28.72	34.04	31.85	99.98 %
807 (wi)	144.7	142.6	32.68	43.60	66.31	32.80	.248	.168	8.40	6.60	22.90	30.56	20.42	26.02	100.00 %
838 (vwi)	145.2	142.8	45.96	34.34	62.54	34.80	.208	.128	6.40	8.60	32.15	24.04	25.08	18.67	99.94 %
844 (vwi)	162.8	160.2	9.61	31.29	119.3	20.46	.264	.184	9.20	5.80	6.00	19.53	28.79	45.68	100.00 %
854 (wi)	140.3	136.9	7.39	72.96	56.53	37.25					5.40	52.51			
870 (vwi)	133.8	131.6	10.38	44.62	76.61	26.20	.224	.144	7.20	7.80	7.88	33.90	30.21	27.91	99.90 %
875 (pi)	125.6	123.4	13.51	59.40	50.46	37.40	.204	.124	6.20	8.80	10.94	48.16	24.00	16.90	100.00 %
938 (vpi)	138.9	137.0	17.89	46.10	73.02	28.52	.144	.064	3.20	11.80	13.05	33.66	41.83	11.36	99.90 %
960 (vpi)	146.7	144.6	31.29	60.50	52.84	41.60	.205	.125	6.25	8.75	21.62	41.80	21.30	15.23	99.95 %

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

	Column	Paragraph	Material	Calculation	997 (fwi)	1016 (fwi)	1026 (vwi)	1033 (fwi)	1206 (pi)
Larger subsample (gm)	AA	5	total moist		111.7	130.9	146.3	127.8	138.8
	A	6	total dry		108.8	127.0	142.3	125.7	136.6
	B	6a	gravel		0.38	8.49	0.11	0.15	13.67
	C	6b	sand		14.26	51.36	10.97	19.21	53.10
	D	6c	silt + clay	A-B-C	94.13	67.19	131.2	106.3	69.80
Smaller subsample (gm)	E	12	total moist	15(AA)/D	17.80	29.28	16.73	18.00	29.80
	F	9a	contents of beaker		.241	.258	.289	.191	.190
	H	9c	sediment in beaker	F-.08	.161	.178	.209	.111	.110
	J	9d	clay	50H	8.05	8.90	10.45	5.55	5.50
	K	9e	silt	15.0-J	6.95	6.10	4.55	9.45	9.50
Entire sample (%)	L	10a	gravel	100B/A	0.35	6.68	0.08	0.12	10.00
	M	10b	sand	100C/A	13.10	40.42	7.71	15.28	38.87
	N	10c	silt	100DK/15A	40.04	21.50	27.94	53.22	32.36
	P	10d	clay	100DJ/15A	46.38	31.36	64.18	31.30	18.74
					99.87 %	99.96 %	99.91 %	99.92 %	99.97 %

Luverne Drift (4 samples)

DATA SHEET--NDGS STANDARD PROCEDURE A-65
GRAVEL-SAND-SILT-CLAY ANALYSIS

	Column	Paragraph	Material	Calculation	360 (fwi)	388 (pi)	439 (vwi)	451 (wi)
	AA	5	total moist		—	—	—	—
Larger subsample (gm)	A	6	total dry		176.4	156.8	163.6	141.6
	B	6a	gravel		3.64	13.83	0.06	4.39
	C	6b	sand		65.25	65.31	34.07	59.29
	D	6c	silt + clay	A-B-C	107.5	72.50	123.8	73.43
Smaller subsample (gm)	E	12	total moist	15(AA)/D	25.00	30.00	20.00	25.00
	F	9a	contents of beaker		.210	.215	.219	.273
	H	9c	sediment in beaker	F-.08	.130	.135	.139	.193
	J	9d	clay	50H	6.50	6.75	6.95	9.65
	K	9e	silt	15.0-J	8.73	8.93	8.54	6.12
Entire sample (%)	L	10a	gravel	100B/A	2.06	8.82	0.04	3.10
	M	10b	sand	100C/A	37.00	41.61	20.82	41.85
	N	10c	silt	100DK/15A	35.43	27.60	43.05	21.15
	P	10d	clay	100DJ/15A	26.40	20.81	35.05	33.35

	360 (fwi)	388 (pi)	439 (vwi)	451 (wi)
	(?) 100.76 %	98.84 %	98.96 %	99.45 %

RATIO OF SAND, SILT, AND CLAY, WITH GRAVEL EXCLUDED

(Cooperstown Drift)

Station	Sand	Silt	Clay	Name*
13	52.2	30.2	17.2	Slightly gravelly sandy loam
22	60.2	21.7	18.0	Sandy loam
43	37.9	42.4	19.6	Gravelly sandy loam
76	53.3	15.4	30.7	Slightly gravelly sandy clay
172	41.0	31.4	28.2	Gravelly sandy loam
184	63.9	23.1	12.5	Slightly gravelly silty sand
271	44.8	33.0	22.3	Slightly gravelly sandy loam
291	31.4	46.4	22.5	Slightly gravelly sandy loam
302	47.9	29.7	22.4	Gravelly sandy loam
308	64.6	28.2	7.3	Muddy (dirty) sandy gravel
329	38.2	42.3	19.6	Gravelly sandy loam
338A	41.6	35.9	21.3	Slightly gravelly sandy loam
338B	41.6	35.0	22.1	Slightly gravelly sandy loam
357	48.5	32.0	19.3	Gravelly sandy loam
411	41.0	41.2	18.2	Slightly gravelly sandy loam
579	53.0	24.3	23.0	Slightly gravelly sandy loam
625	18.5	51.6	29.5	Slightly gravelly sandy loam

Station	Sand	Silt	Clay	Name*
646	38.1	41.9	19.2	Gravelly sandy loam
659	48.9	37.5	13.4	Gravelly silty sand
694	37.7	46.7	15.3	Slightly gravelly sandy silt
700	42.0	28.6	29.0	Slightly gravelly sandy loam
716	40.6	34.2	25.4	Gravelly sandy loam
722T	50.8	31.7	18.0	Slightly gravelly sandy loam
728	57.6	33.3	9.7	Slightly gravelly silty sand
771	60.4	21.8	17.3	Gravelly sandy loam
780	30.1	35.8	33.5	Slightly gravelly sandy loam
807	39.7	26.5	33.8	Gravelly sandy loam
838	35.4	36.9	27.5	Muddy (dirty) gravel
844	20.8	30.7	48.6	Slightly gravelly clay
870	36.8	32.8	30.4	Slightly gravelly sandy loam
875	54.0	27.0	19.0	Gravelly sandy loam
938	38.7	48.1	13.0	Gravelly sandy silt
960	53.6	27.3	19.5	Gravelly sandy loam
997	13.1	40.0	46.4	Slightly gravelly clay loam
1016	43.5	23.2	33.8	Slightly gravelly sandy loam
1026	7.7	27.9	64.2	Slightly gravelly clay
1033	15.3	53.2	31.3	Slightly gravelly
1206	43.2	36.0	20.8	Gravelly sandy loam

*Terminology from Clayton, 1965 (unpublished).

RATIO OF SAND, SILT, AND CLAY, WITH

GRAVEL EXCLUDED

(Luverne, McHenry, and Kensal Drifts)

Station	Sand	Silt	Clay	Name*
L 360	37.7	36.2	26.9	Slightly gravelly sandy loam
L 388	46.2	30.7	23.1	Slightly gravelly sandy loam
L 439	20.8	43.0	35.0	Slightly gravelly sandy loam
L 451	42.6	22.0	34.7	Slightly gravelly sandy loam
M 6A	56.8	25.5	17.3	Gravelly sandy loam
M 7A	62.8	27.8	9.8	Gravelly silty sand
M 8A	40.7	47.7	11.4	Slightly gravelly sandy silt
M 12A	54.0	37.4	8.2	Slightly gravelly silty sand
M 1145	41.5	24.4	34.6	Gravelly sandy loam
M 1167	40.5	35.3	23.9	Gravelly sandy loam
M 1196	12.6	70.2	15.7	Slightly gravelly silt loam
M 1218	53.8	31.9	14.6	Gravelly silty sand
M 1223	48.1	34.3	17.1	Gravelly sandy loam
M 1254	42.2	29.4	28.3	Gravelly sandy loam
K 138B	32.3	35.1	32.4	Slightly gravelly sandy mud
K 138T	40.0	33.0	26.9	Gravelly sandy mud
K 1262	42.2	36.1	21.5	Slightly gravelly sandy mud

Station	Sand	Silt	Clay	Name*
K 1265	32.5	40.5	26.6	Slightly gravelly sandy mud
K 1269	19.3	43.2	35.9	Slightly gravelly sandy mud
K 1270	77.9	12.8	9.5	Silty sand
K 1274	33.0	36.8	30.4	Slightly gravelly sandy mud
K 476	10.0	58.8	29.9	Slightly gravelly mud
K 904	29.1	59.9	10.9	Slightly gravelly sandy silt
K 1101	60.4	31.2	8.0	Slightly gravelly silty sand

L = Luverne Drift

M = McHenry Drift

K = Kensal Drift

*Terminology from Clayton, 1965 (unpublished).

AVERAGE GRAIN SIZE ANALYSIS OF TILLS
BY DRIFT SHEET

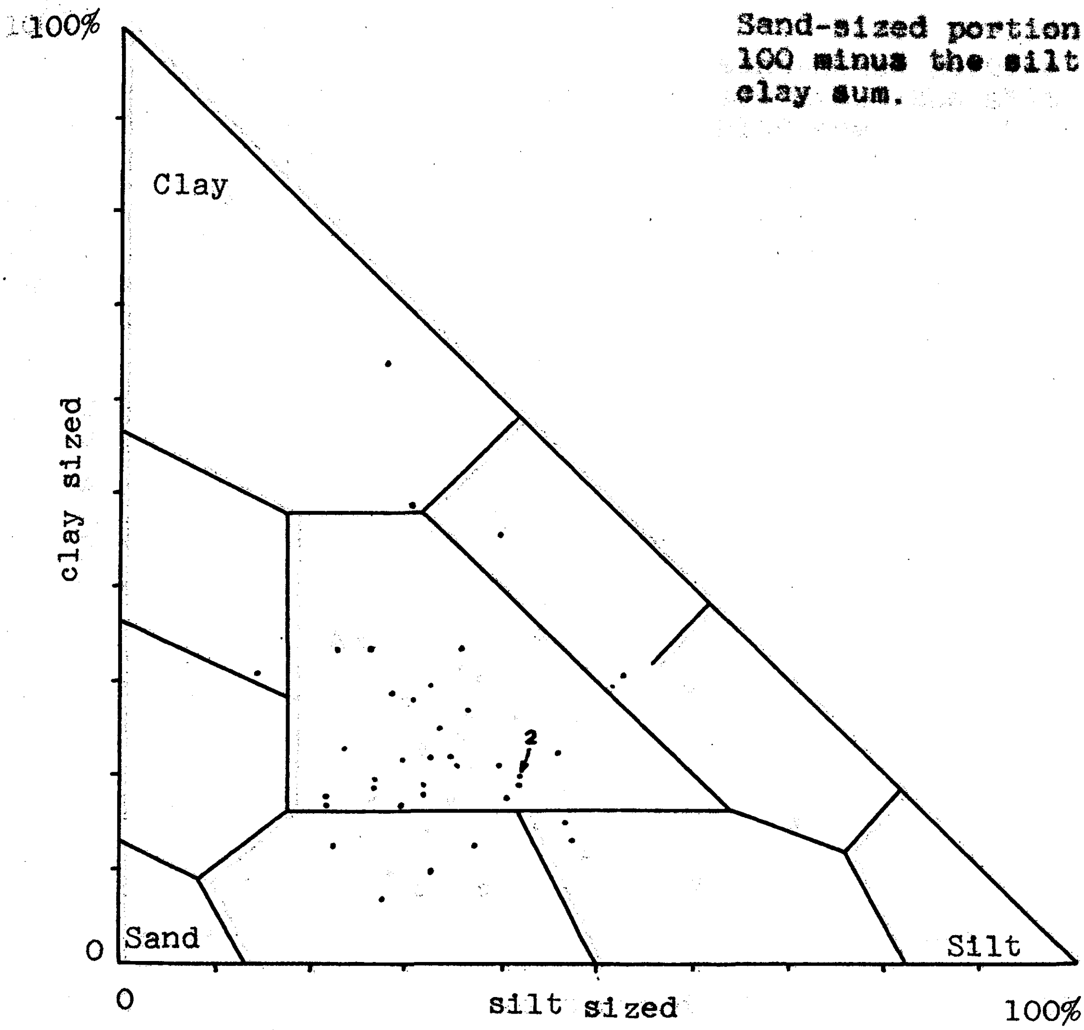
	Percentage*			
	Sand	Silt	Clay	Gravel
Luverne Drift	37	33	30	3.5
Cooperstown Drift	42	34	24	10.2
McHenry Drift (average)	46	36	18	11.0
"normal" drift area	37	39	24	11.2
collapsed end moraine	54	34	12	10.7
Kensal Drift (average)	38	39	23	4.1
north of outwash area	40	34	26	2.2
south of outwash area	34	50	16	5.0

*sand, silt, and clay ratios are exclusive of gravel; gravel is percentage of the total sample.

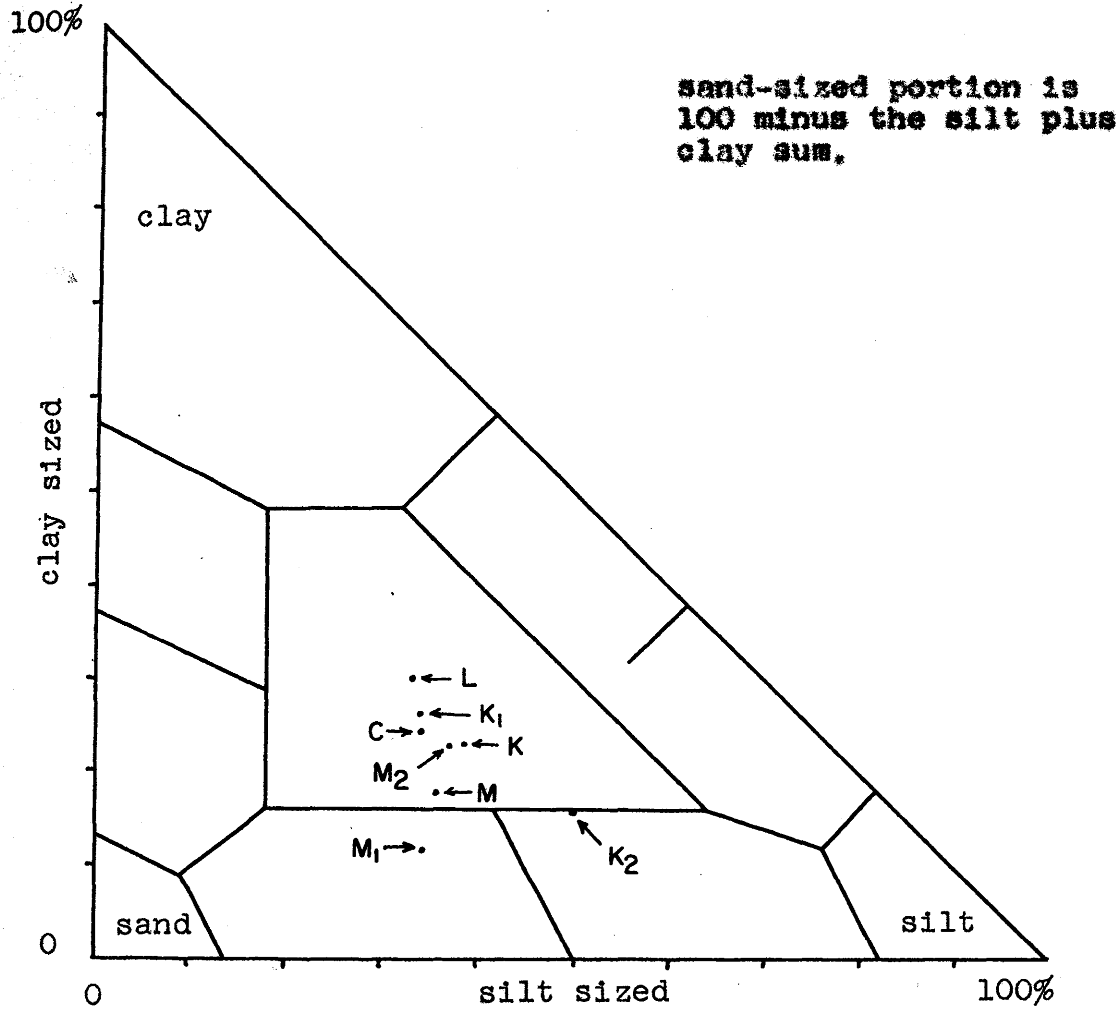
GRAIN SIZE DISTRIBUTION OF COOPERSTOWN DRIFT

(exclusive of gravel)

Sand-sized portion is 100 minus the silt plus clay sum.



AVERAGE GRAIN SIZE DISTRIBUTION OF DRIFTS IN NORTHERN GRIGGS COUNTY, NORTH DAKOTA



L - Luverne Drift
C - Cooperstown Drift
M - McHenry Drift average
M_1 - McHenry Drift (collapsed)
M_2 - McHenry Drift (not collapsed)
K - Kensal Drift average
K_1 - Kensal Drift (north of outwash)
K_2 - Kensal Drift (south of outwash)

APPENDIX II

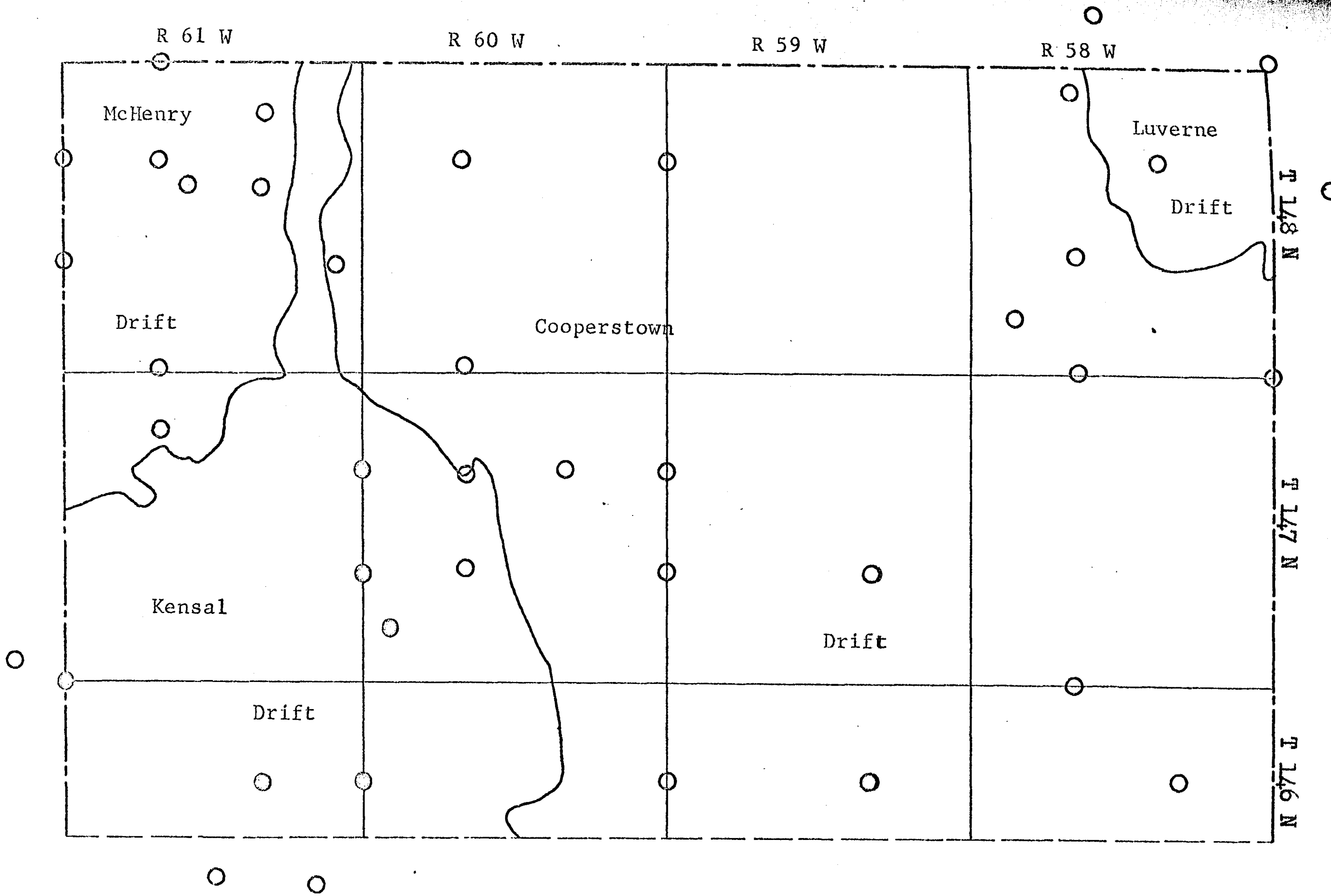
MAJOR PEBBLE TYPES IN TILL OF NORTHERN GRIGGS COUNTY

Approximately 7,500 pebbles from 34 sample sites (Figure 22) were identified to determine whether the four drift sheets exposed in the area had unique pebble concentrations by which they could be differiented. The pebbles were examined using two different techniques. In the first method, the pebbles were separated into 10 categories by counting the number of times a distinct pebble type occurred in a given till sample. Actual counting of the pebbles proved to be difficult, however, because the shale pebbles, and to a lesser extent the igneous pebbles, break-up readily and yield abnormally high counts. Results of this portion of the study indicate that although the various drift sheets have slightly different pebble-type concentrations, only the shale and carbonate pebble concentrations differ significantly.

The second method of analyzing the pebble concentrations was initiated to compensate for the disintegration of shale pebbles and to utilize only these portions of the pebbles which differed significantly in a given drift sheet. For this reason, the pebbles were grouped into three categories (shale, carbonate, and other) and a weight percentage rather than an actual count was used to record their concentrations.

Results of this test indicate that although differences in pebble-type concentrations do exist, they are not significant and cannot be used to differentiate the four drift sheets. Another result of the study, indicates that the Cooperstown drift contains only about one-half of the shale that is found in the other three drift sheets. This fact is interesting because the Cooperstown drift is the thinnest and is the closest to a local source of pebbles from the Cretaceous Pierre shale. It cannot be concluded, however, that this drift had a different source area than the other three drifts, because the Luverne till is believed to have been deposited during a recessional phase of the Cooperstown ice.

A secondary purpose of this study was to determine if different size groups of pebbles had distinct concentrations of a given pebble type. Four samples from the Luverne drift and six samples from the Cooperstown drift were used in this study. In the Luverne samples, pebbles ranging from 2.0 to 5.6 mm in diameter were classified as fine and pebbles with diameters greater than 5.6 mm were classified as coarse pebbles. In the Cooperstown samples, pebbles with diameters of 2.0 to 4.0 mm were classified as fine while pebbles with diameters greater than 4.0 mm were classified as coarse. The pebbles were again placed into 10 categories and counted as in the first portion of this study. In recording the results, however, only the weight percentages of shale, carbonate, and other pebbles were utilized. The results indicate that about 15% fewer carbonate pebbles, 19% more shale pebbles, and 2% fewer other pebbles are found in the fine size range. For this reason, it is felt that the size of the pebbles analyzed in any comparable study must be recorded.



○ - not included in actual count

Figure 22. Pebble count location sites in northern Griggs County

[illegible]

No.	Shale*	Ls & Dolo	Iron Conc	Organitic	Coarse-gn Ign Lt	Coarse-gn Ign Dk	Fine-gn Igneous Lt	Fine-gn Igneous Dk	Qtzite	Misc	Total
13	35	119	6	17	63	19	0	108	5	7	379
20	?	8	1	1	2	3	0	0	0	0	15+
43	163	32	4	6	9	8	0	26	1	2	251
172	0	85	0	12	23	5	2	77	7	7	218
357	7	243	10	18	36	7	0	23	3	10	362
411	?	49	9	11	12	3	0	16	1	1	104+
291	?	45	13	9	24	4	1	9	4	0	109+
308	189	65	10	24	24	15	0	5	0	17	349
579	19	80	2	40	30	9	1	35	7	7	228
659	163	39	31	12	16	1	0	12	0	2	276
722T	103	21	3	5	10	1	0	12	0	1	156
716	36	95	4	30	30	8	0	20	5	3	211
838	87	115	8	20	26	71	0	19	4	5	356
938	130	13	10	2	5	1	0	7	2	2	180
960	90	68	7	22	19	10	0	14	1	5	236
1016	90	62	10	15	27	12	0	13	2	2	233
1206	109	42	0	12	11	3	0	5	0	2	184

*Shale count is approximate
?Count would be unreliable
+Total pebbles less shale

PEBBLE TYPES IN LUVERNE, KENSAL, & McHENRY TILLS

Drift	No.	Shale**	Ls & Dolo	Iron Conc	Gran-itic	Coarse-gn Ign Lt	Coarse-gn Ign Dk	Fine-gn Igneous Lt	Fine-gn Igneous Dk	Qtzite	Misc	Total
Luverne	1	141	39	3	10	19	2	1	10	9	10	244
Luverne	2	262	204	5	31	26	9	0	52	8	23	620
Luverne	3	126	102	14	11	25	14	4	20	1	13	333
Luverne	4	156	30	12	4	3	3	2	4	0	2	216
Luverne	451	35	39	0	2	16	3	0	12	2	1	110
Kensal	138T	?	64	13	4	14	2	0	6	4	3	110+
Kensal	904	36	37	1	7	47	1	0	19	6	0	154
Kensal	1262	10	71	11	6	45	12	8	21	2	6	192
Kensal	1274	?	30	8	2	23	1	0	15	1	2	82 +
McHenry	5	?	38	4	4	10	8	1	14	0	6	85+
McHenry	6A	?	96	5	8	36	1	0	24	5	3	178+
McHenry	7A	?	61	3	1	43	49*	0	18	7	7	189+
McHenry	16	?	26	1	2	19	9	0	2	0	3	62+
McHenry	1145	?	48	5	5	40	3	0	13	4	4	122+
McHenry	1167	?	92	2	25	43	9	2	30	6	7	216+
McHenry	1223	38	26	1	3	14	6	0	7	1	2	99
McHenry	1254	0	171	3	26	108	24	32*	16	6	8	394

*Abnormally high reading due to breakup of pebbles
**Shale count is approximate
?Count would be unreliable
+ Total pebbles less shale

[illegible]

(Averages by Drift Sheet)

Drift	Shale*	Ls & Dolo	Iron Conc	Gran-itic	Coarse-gn. Ign Lt	Coarse-gn. Ign Dk	Fine-gn Ign Lt	Fine-gn Ign Dk	Qtzite	Misc
Luverne	144	84	5	14	18	6	1.5	20	4	10.5
Kensal	?	51	8	5	32	4	2	15	3	3
McHenry	?	68	3	9	39	8	0.5*	15	4	5
Cooperstown	100	69	7.5	15	21.5	10.5	0.5	24	3.5	4

*Shale count is approximate

?Count would be unreliable

WEIGHT COMPARISON OF PREDOMINANT PEBBLE TYPES IN TILL
(Cooperstown drift)

Sample No.	Actual Weight (gm)			Weight Percentages		
	Shale	Carbonate	Other*	Shale	Carbonate	Other*
13	0.59	8.22	12.69	2.7	38.3	59.0
20	51.10	534.30	12.30	8.6	89.5	2.1
43	7.68	20.42	22.20	15.3	40.6	44.1
172	0.00	17.30	10.10	0.0	63.2	36.8
291	3.66	22.69	4.90	11.7	72.6	15.7
308	13.78	29.50	24.09	20.5	43.8	35.8
357	0.11	30.32	7.01	0.3	81.0	18.7
411	14.60	6.70	2.80	60.6	27.8	11.6
579	0.50	3.75	5.75	5.0	37.5	57.5
659	8.09	13.31	7.70	27.8	45.7	26.5
716	2.73	11.51	13.55	9.8	41.4	48.8
722T	2.20	2.78	1.86	32.2	41.6	27.2
838	1.76	24.32	102.07	1.4	19.0	79.6
938	4.93	7.53	4.30	29.4	44.9	25.7
960	3.90	27.19	10.69	9.6	65.0	25.6
1016	1.75	5.79	7.00	12.0	39.8	48.2
1206	4.24	7.19	2.68	30.0	51.0	19.0

*"Other" includes igneous, metamorphic, and all other sedimentary pebbles.

WEIGHT COMPARISON OF PREDOMINANT PEBBLE TYPES IN TILL

(Luverne, Kensal, and McHenry drifts)

Sample No.	Actual Weights (gm)			Weight Percentages		
	Shale	Carbonate	Other*	Shale	Carbonate	Other*
1 (L)	81.20	68.20	40.80	42.7	35.9	21.4
2 (L)	24.30	146.60	109.50	8.6	52.3	39.1
3 (L)	35.20	343.10	317.70	5.1	49.3	45.6
4 (L)	87.60	29.50	22.10	62.9	21.2	15.9
451 (L)	0.47	2.20	0.90	13.2	61.6	25.2
138T (K)	4.91	12.38	1.49	26.1	65.9	8.0
904 (K)	0.50	5.40	2.40	6.0	65.0	29.0
1262 (K)	0.10	3.21	6.42	1.0	33.0	66.0
1274 (K)	7.63	1.30	1.21	75.3	12.8	11.9
5 (M)	91.70	65.00	113.30	34.0	24.0	42.0
6A (M)	13.40	5.30	1.90	65.0	25.7	9.3
7A (M)	11.80	9.90	2.70	48.3	40.6	11.1
16 (M)	55.10	80.30	116.90	21.8	31.8	46.3
1145 (M)	2.70	18.90	3.80	10.6	74.4	15.0
1167 (M)	1.30	17.80	6.80	5.0	68.9	26.1
1223 (M)	0.47	23.77	1.42	1.8	92.6	5.5
1254 (M)	0.00	61.70	128.70	0.0	32.4	67.6

*Other includes igneous, metamorphic, and all other sedimentary pebbles.
(L) = Luverne drift
(K) = Kensal drift
(M) = McHenry drift

AVERAGE WEIGHT PERCENTAGES OF PREDOMINANT

PEBBLE TYPES IN TILL

(by drift sheet)

Drift	Actual Weight (gm)			Weight Percentages		
	Shale	Carbonate	Other*	Shale	Carbonate	Other*
Luverne	45.8	117.9	78.2	19.0	48.7	32.2
Kensal	2.3	5.6	2.9	21.3	51.8	26.9
McHenry	22.1	35.3	46.9	21.2	33.8	45.0
Cooperstown	7.2	45.4	14.8	10.5	67.4	22.0

*"Other" includes igneous, metamorphic, and all other sedimentary pebbles.

COMPARISON OF PEBBLE TYPES BY SIZE

(Cooperstown Drift)

No.	Shale*	Ls & Dolo	Iron Conc	Gran-itic	Coarse-gn Ign Lt	Coarse-gn Ign Dk	Fine-gn Igneous Lt	Fine-gn Igneous Dk	Qtzite	Misc	Total
308F**	122	30	4	13	15	7	0	4	0	9	204
308C***	67	35	6	11	9	8	0	1	0	8	145
716F	23	58	3	21	21	7	0	9	3	1	146
716C	13	37	1	9	9	1	0	11	2	2	65
838F	78	88	7	14	20	63	0	13	4	2	289
838C	9	27	1	6	6	8	0	6	0	3	66
43F	53	9	1	1	0	2	0	9	1	1	77
43C	110	23	3	5	9	6	0	17	0	1	174
659F	115	21	21	11	14	0	0	10	0	2	194
659C	48	18	10	1	2	1	0	2	0	0	82
960F	70	39	5	11	15	6	0	8	1	3	153
960C	20	29	2	11	4	4	0	6	0	2	78

*Shale count is approximate
**F = fine (2 to 4 mm diameter)
***C = course (greater than 4 mm diameter)

[illegible]

(Luverne Drift)

No.	Shale*	Ls & Dolo	Iron Cone	Gran-itic	Coarse-gn Ign Lt	Coarse-gn Ign Dk	Fine-gn Igneous Lt	Fine-gn Igneous Dk	Qtzite	Misc	Total
1F**	81	24	1	4	17	2	1	8	7	2	147
1C***	60	15	2	6	2	0	0	2	2	8	97
2F	160	136	5	23	15	3	0	36	8	7	403
2C	102	68	0	8	11	6	0	16	0	6	217
3F	87	53	2	5	18	11	1	12	1	11	201
3C	39	52	12	6	7	3	3	8	0	2	132
4F	104	16	8	3	3	3	1	2	0	2	142
4C	52	14	4	1	0	0	1	2	0	0	74

*Shale count is approximate

**F = fine (2.0 to 5.613 mm diameter)

***C = course (greater than 5.613 mm diameter)

WEIGHT PERCENTAGE DIFFERENCES WITH DIFFERENT SIZE PEBBLES

Drift	Station	Carbonate	Shale	Other
Luverne	1	20% less*	10% more**	10% more
Luverne	2	10% less	15% more	5% less
Luverne	3	13% less	23% more	10% less
Luverne	4	2% less	2% less	4% more
Average:		11% less	12% more	1% less
Cooperstown	43	17% less	30% more	13% less
Cooperstown	308	23% less	23% more	Same
Cooperstown	659	30% less	23% more	7% more
Cooperstown	716	Same	2% less	2% more
Cooperstown	838	23% more	26% more	36% less
Cooperstown	960	41% less	19% more	15% more
Average:		15% less	19% more	4% less
GRAND AVERAGE (both drifts):		13% less	15% more	2% less

*less = fewer pebbles in fine size ranges

**more = more pebbles in fine size range

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