NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, *State Geologist*

Bulletin 36

NORTH DAKOTA STATE WATER CONSERVATION COMMISSION

MILO W. HOISVEEN, *State Engineer*

County Ground Water Studies I

GEOLOGY AND GROUND WATER RESOURCES OF KIDDER COUNTY, NORTH DAKOTA

PART 1 GEOLOGY

by

Jon L. Rau, Wallace E. Bakken, James Chmelik
and Barrett J. Williams

GRAND FORKS, NORTH DAKOTA
1962

Price $1.50

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

CONTENTS

ILLUSTRATIONS

Plate

Figures

Table

ABSTRACT

Kidder County was covered with glacial ice at least three times during the Wisconsin Stage of the Pleistocene, but the entire sequence of drifts has not been observed in one exposure.

The drift which covers the area was deposited during three ice advances termed the Long Lake, Burnstad and Streeter advances. The position of the drift border of the Long Lake advance is marked by the prominent Long Lake end moraine on the western border of the county.

The Twin Buttes end moraine and associated dead-ice moraine was deposited by the Burnstad ice in southeastern Kidder County. The Burnstad drift overlaps the Long Lake drift on the west, and is in turn overlain by the Streeter drift on the east.

The drift of the Streeter advance occurs in a north-trending belt over 45 miles long in the eastern part of the county. The Streeter drift represents a readvance of the same ice sheet that deposited the Burnstad drift. The major arcs of end moraine which mark the drift border of this advance have been herein named from north to south the Woodhouse Lake, Lake Williams, McPhail Butte, Crystal Springs and Lake George Loops. Each is a relatively high end moraine bordered by outwash and dead-ice moraine.

Dead-ice moraine results from the melting of stagnant ice over wide areas. It is characterized by high local relief, numerous kettles, and random oriented ridges.

Each ice advance has been slowed and finally halted by the outlying buttes and mesas which comprise the eastern border of the Coteau du Missouri in central North Dakota. Each major ice advance was followed by a prolonged period of stagnation and melting resulting in the deposition of widespread deposits of dead-ice moraine behind the end moraines and vast sheets of outwash in front of their termini.

The physical characteristics of the tills are similar. Grain analyses of 47 samples of till from throughout the county show no significant differences in the size composition of tills. Only subtle differences exist in the color and pebble composition of the tills in the different moraines.

INTRODUCTION

Scope and purpose of study

This portion of the report describes the glacial geology of Kidder County, which embraces 1,152 square miles in the center of the state of North Dakota (Fig. 1). The map, Plate 1, shows the distribution of the various glacial deposits in the county and the areas where bedrock appears at the surface.

The benefits expected to accrue from this project include the location of highway construction materials, a geologic map to aid engineers in the selection of routes and construction sites and to indicate areas where ground-water is likely to be available in large quantities for irrigation.

The present report is the result of a reconnaissance study and its purpose is to describe the major glacial features and deposits of Kidder County and to reconstruct the glacial history of this part of North Dakota. Moreover, it provides information to substantiate the regional reconnaissance of the glacial geology of North Dakota by Lemke and Colton (1958).

Field Work and Acknowledgements

This report is the result of one field season of study completed during the summer of 1959. Mapping was done by road traverse with study of exposures in road, railway, and lakeshore cuts. The field data were plotted on air photographs and on a planimetric map of Kidder County, scale one inch to the mile, prepared by the North Dakota State Highway Department.

The field work was divided equally among four authors, under the supervision of the senior author. The three junior authors completed reports of their respective areas in partial fulfillment of the requirements for the Master's degree in geology at the University of North Dakota.

The senior author was assisted in the field by Lee Clayton, who also made grain analyses of samples of till and wrote part of the chapter on the physical characteristics of the tills. We have benefited from field conferences with Wilson M. Laird, State Geologist.

We have used information provided by test-borings made by the Ground Water Branch of the Water Resources Division of the United States Geological Survey, in cooperation with the North Dakota Geological Survey and the State Water Conservation Commission.

Previous Work

The glacial deposits in Kidder County were first discussed by T. C. Chamberlin (1883) who made a reconnaissance map of the "Terminal Moraine of the Second Glacial Epoch" and his map indicates the position of the major moraines of the area.

In 1896, J. E. Todd reported on the "Moraines of the Missouri Coteau and their Attendant Deposits." Todd's map shows the major features of the "First or Altamont Moraine" and the "Second or Gary Moraine" in the southern part of the County.

H. A. Hard and Harold McKinstry (1910, p. 61-80) described the soils of the Dawson area, Kidder County. Their survey included T. 139 N., and T. 140 N., R. 70 W. to R. 74 W., and an east-west strip twelve miles wide across the County. They report four distinct soil types with different sand and clay phases supported by the results of mechanical analyses. In addition to the surface soil types shown on their map, they describe deeper subsoil types and relate them to the lakes and topographic features, such as the sandy plains and stony uplands of the "Gary" moraine.

M. R. Campbell (1916) made a field examination in 1914 of the route of the Northern Pacific Railroad. He showed the distribution of the "Gary" and "Altamont" moraines adjacent to the railroad and indicated that the "Altamont" moraine was formed by the Wisconsin ice sheet at its maximum advance.

Q. F. Paulson (1952) included a small part of the southeastern corner of Kidder County in his report on the ground-water resources and glacial geology of the Streeter area in Stutsman County.

The monographic treatment of the Pleistocene geology of eastern South Dakota by Flint (1955) has enhanced the correlation of the different drift sheets of Kidder County with those of South Dakota and has provided a regional framework for study of the history of the Pleistocene in the Dakotas.

D. R. Moir (1957) reported on the occurrence and age of cones from white spruce trees buried in moraine in southeastern Kidder County.

A summary of the Pleistocene geology of North Dakota was prepared by Lemke and Colton (1958) for the 9th Annual Field Conference of the Midwestern Friends of the Pleistocene. Further, they have completed a generalized geologic map of the glacial deposits of North Dakota.

GEOGRAPHY

COTEAU DU MISSOURI

The Coteau du Missouri is that part of the Glaciated Missouri Plateau section of the Great Plains province which lies east of the Missouri River (Fenneman, 1930). The Coteau extends diagonally from the northwest corner of North Dakota to the center of the southern boundary of the State, where it crosses into South Dakota and is a dissected highland which has been buried by glacial drift in Kidder County.

Beneath the glacial drift in Kidder County, the uppermost bedrock formation is generally the Fox Hills Sandstone, which dips gently to the west, except in the southwestern corner of the county where a broad open fold is indicated from a study of several outcrops adjacent to Lake Etta and Long Lake.

The topography of this area is mainly due to glacial deposition over the rounded buttes and mesas and valley floors of the Coteau. The glacial deposits include end, ground, and dead-ice moraines, ice-contact stratified drift, and outwash. A large part of the county is characterized by knob-and-kettle topography, which is due mainly to extensive deposits of dead-ice moraine. The effects of glacial erosion on the bedrock are generally concealed beneath the mantle of drift. Glacial ice has reduced the local bedrock relief by abrading and reducing the elevation of the higher bedrock areas, by filling the larger valleys with drift, and by completely obscuring the small valleys. The result has been a great expanse of rounded, treeless hills of different heights with well-grassed and boulder-strewn slopes. Between the hills occur many meadows, marshes, and small lakes.

The maximum relief in the county is nearly 500 feet.

Lakes

The Coteau du Missouri is dotted with many lakes, and Kidder County contains several which exceed 3 miles in length. These larger lakes (Plate 1), such as Long Lake and Horsehead Lake, are situated in the partly buried valleys of the preglacial rivers. Long Lake, Lake Etta, and Lake Isabel are all related to the buried valley of the ancestral Cannonball River, and Horsehead Lake is apparently related to the old valley of the ancestral Wing River, which trended southeast into the ancestral Cannonball River in the central part of the county (Figure 16). The majority of the small lakes are restricted to large depressions or kettles in the dead-ice and end moraine.

Lakes are more abundant in the northern part of the county in the dead-ice moraine where the surface of the moraine ranges from 50 to 200 feet higher than in the central and southern areas. The till-floored depressions hold water longer than does the interior plain of outwash where much of the water disappears by infiltration through sand and gravel deposits.

Most of the lakes are saline because evaporation exceeds recharge by rainwater during most of the summer months.

The borders of nearly all the lakes are lined with boulders which have accumulated at the base of wave-cut cliffs as a residual deposit from the till.

CLIMATE

Kidder County is included in the climatic province of the semiarid Great Plains, which is characterized by variable annual precipitation, long and severe winters, and rather short and hot summers. The area lies in the path of most of the storms sweeping across central North Dakota from the Pacific coast, but the air currents have lost most of their moisture in crossing the high mountain chains to the west.

The highest temperature ever recorded by a U. S. Weather Bureau station in North Dakota is 124° at Medora in Billings County on September 3, 1921. The lowest official temperature on record is -60° at Parshall in Mountrail County on February 15, 1936.

The growing season (the period between the latest and the earliest killing frost) at Steele, North Dakota, averages 112 days.

The average precipitation in Kidder County is 17.1 inches and the mean annual temperature is 40.6°. The coldest month is January, which averages 7.6° and the hottest month is July, which averages 70.5°.

The crop growth is influenced by the length of the growing season, the large number of clear days during the season, and the fact that more than half the annual rainfall comes during the summer months. The success or failure of wheat and other crops depends not only on the location of the local summer showers, but also on their timing.

Relatively high winds are common during the winter and spring months and gales accompany local thunderstorms of the summer months.

Climatic summary for Kidder County and vicinity, North Dakota (Bavendick, 1959):

Station
    Steele, North Dakota

County
    Kidder

Temperature (mean)	
Length of record (years)	25 (1931-1955)
January	7.6
February	11.6
March	23.0
April	41.3
May	54.3
June	63.0
July	70.5
August	68.3
September	58.1
October	45.9
November	27.4
December	14.7
Annual	40.6
Freeze Data*	
Freeze threshold temperature	32.0
Mean date of last Spring occurrence	05-24
Mean date of first Fall occurrence	09-13
Mean number of days between dates	112
Year of record (Spring)	30
Number of occurrences in Spring	30
Years of record (Fall)	30
Number of occurrences in Fall	30

* A freeze is a numerical substitute for the former term "killing frost" and is the occurrence of a minimum temperature at or below the threshold temperature of 32°, 28°, etc.

Precipitation (mean)	
Length of record (years)	25 (1931-1955)
January	.44
February	.37
March	.60
April	1.32
May	2.26
June	3.88
July	2.51
August	2.04
September	1.71
October	1.20
November	.45
December	.32
Annual	17.10

SOILS

The dominant zonal soil type in Kidder County is the Chestnut soil (U. S. Department of Agriculture, Yearbook 1941, p. 117). The zonal soil is a broad geographic unit which reflects the climate and ecologic complex under which it matures. The Chestnut zonal soil has a dark brown surface horizon which grades below into lighter colored soil and a horizon of lime accumulation. It is usually developed under mixed tall and short grasses in a subhumid to semiarid climate and grades into the Chernozem soil (U. S. Department of Agriculture, 1938, p. 1164). The Chestnut soil develops on the arid side of the Chernozem soil and contains less organic matter and even less lime.

BIOGEOGRAPHY

The biogeographic zone in the Great Plains which included Kidder County is the steppe where the native vegetation consists of grasses. Trees are confined to lake shores, bottoms of a few stream valleys, and in the gullies of the higher hills in the northern part of the county. The most common native grasses are the western wheat grass, quack grass, buffalo grass, and cord grass.

Distichlis spicata is the most common plant in the broad shallow depressions of the kettles and dry alkali flats (Bergman, 1912, p. 164). On the higher knolls, short prairie grasses are common, especially where the soil is shallow and stony.

The farmers commonly raise wheat in the lowlands and graze cattle in the higher areas of end and dead-ice moraine where sufficient water is present.

PRE-PLEISTOCENE SURFACE GEOLOGY
STRATIGRAPHIC SEQUENCE AND LITHOLOGY

The bedrock which directly underlies the mantle of glacial drift in Kidder County is of Cretaceous and Tertiary Age. Four different rock formations are present beneath the glacial deposits. The oldest rocks beneath the drift are the Pierre Shale and the Fox Hills Formation, both of which are Upper Cretaceous in age and occur immediately below the glacial deposits in a large part of the county. In the remainder of the county, the Cannonball and Tongue River Formations crop out beneath the drift and are included in the Fort Union Group, which is of early Tertiary (Paleocene) Age.

The stratigraphy of the bedrock which underlies the drift is as follows:

TERTIARY SYSTEM
  Paleocene Series
    Fort Union Group
      Tongue River Formation
      Cannonball Formation

CRETACEOUS SYSTEM
  Upper Cretaceous Series
    Montana Group
      Fox Hills Formation
      Pierre Shale

The geologic map (Plate 1) shows the areas where the bedrock crops out in Kidder County. The distribution of the bedrock units is shown on the geologic map of North Dakota (Hansen, 1956).

CRETACEOUS SYSTEM
  Upper Cretaceous Series
    Montana Group

Pierre Shale

The Pierre Shale is bluish gray to dark gray and weathers into small flaky fragments which show spots of iron oxide. The upper beds of the Pierre contain many fossiliferous concretions, which range in size from 1 inch to 8 feet (Leonard, 1912, p. 40-41).

Fox Hills Formation

The Fox Hills Formation is grayish yellow in color, but weathers yellow and brown and becomes poorly consolidated at the surface. Crossbedding is common and the sandstone contains small ferruginous concretions and twisted stemlike forms. The rock consists mainly of medium-grained quartz sand. The Fox Hills Formation commonly crops out in roadcuts in the Lake George area of the southeastern corner of the county. The best exposures of the Fox Hills Sandstone occur in the Sibley Buttes on the west side of Horsehead Lake in the center of the county.

TERTIARY SYSTEM
  Paleocene Series
    Fort Union Group

Cannonball Formation

The Fort Union Group contains as its lowermost unit in this area the Cannonball Formation. It consists of light to dark brownish gray sandstone and dark gray marine shales that contain an abundant fauna of pelecypods, gastropods, foraminiferids, and sharks' teeth. Only one exposure of the Cannonball Formation has been positively identified in Kidder County; it is located in the NE¼ SE¼ Section 18, T. 143 N., R. 73 W. The age of the bedrock was directly determined by the identification of a small cone-like fossil (**Dentalium (Laevidentalium) pauperculum,** Meek and Hayden) belonging to the Phylum Mollusca, which dated the rock as Paleocene in age.

Tongue River Formation

The Tongue River Formation is commonly light tan to yellow and white sandstone which weathers yellowish brown with lesser amounts of sandy, gray, limonitic shale, which is locally gypsiferous. It occurs immediately beneath the drift in the northwestern corner of the county, and probably is the formation comprising the bedrock highs in that part of the county. The Tongue River Formation crops out in several places in T. 143 N., R. 74 W., and R. 73 W., in northwestern Kidder County.

Glacial Erosion of the Bedrock

The exposed bedrock does not exhibit glacial markings. The absence of such markings can be explained by the fact that the rock exposed to erosion by glacial ice is relatively weak, i. e., the Fox Hills Sandstone is soft and friable, the Pierre Shale is soft and fissile, and the rocks of the Fort Union Group are mostly poorly consolidated sands and clay. The sandstone ledges of the Fox Hills Formation have been especially affected by ice-shove in the vicinity of the Sibley Buttes, where the originally horizontal beds have been displaced to high angles.

Structure

The regional dip on the Fox Hills Sandstone is 2 or 3 degrees to the northwest into the Williston Basin. Most of the outcrops of Fox Hills Sandstone are very nearly horizontal.

A broad breached north trending anticline occurs south of Long Lake. The southeast limb is partly exposed in a 1 mile long northeast trending hogback 7 miles south of Lake Etta in Section 33, T. 137 N., R. 73 W., where the Fox Hills Sandstone dips 3 to 5 degrees southeast. The reverse dip is clearly discernible on air photographs of the area. The southwest closure occurs in 3 roadcuts north of Long Lake in Sections 10, 16, and 17, T. 138 N., R 74 W. The dip on these outcrops of the Fox Hills, 1 mile north of the center of the lake, is 2 to 3 degrees to the southwest. The northeast dip occurs in Section 35, T. 139 N., R. 73 W., where the sandstone dips 3 degrees northeast. The regional dip to the northwest apparently produces closure in this fold. The size of the structure seems to warrant the drilling of test wells to determine its extent at depth. Anomalous structural features associated with Sibley Buttes are discussed elsewhere in this report.

PLEISTOCENE GEOLOGY

Introduction

All of North Dakota, with the exception of the southwest corner, was glaciated during the Pleistocene. No definite evidence of pre-Wisconsin glaciation has been found in the State, but glacial deposits, tentatively identified as ranging in age from the Iowa substage of the Wisconsin to at least Two Creeks interstadial, have been recognized (Lemke and Colton, 1958, p. 43).

A sample of peat from a gravel pit in Section 32, T. 135 N., R. 72 W., Logan County, North Dakota (laboratory sample number W990) was dated at greater than 38,000 years B.P. by the United States Geological Survey. This date places the sample either in the Altonian Substage as defined by Frye and Willman (1960, p. 2-3) or possibly in deposits older than the Wisconsinan.

The distribution of the major moraines indicates that glacier ice entered the county from the north and east and followed the bedrock lows before it overrode the upland surface.

The glacial drift is divisible into four types: till, outwash, glacial lake deposits, and ice-contact stratified drift.

Till is generally fine-grained unstratified and unsorted ice-laid material which can consist of any combination of materials from clay to boulder size. It is the most abundant material in the glacial deposits of Kidder County.

Outwash is stratified drift that is stream deposited or washed out beyond the glacier (Flint, 1957, p. 136). The outwash plain embraces nearly 350 square miles in central Kidder County.

Glacial lake deposits consist chiefly of laminated silt and clay and indicate areas where ponded waters collected sediment from streams.

Ice-contact stratified drift is a body of sand and gravel built in immediate contact with wasting ice. These features include eskers, kame terraces, kames, and kettle chains (Flint, 1957, p. 136).

Physical Characteristics of Tills

Flint (1955, p. 60) has found in South Dakota that a lateral change in bedrock beneath the till accompanies a similar change in the character of the overlying drift. This was not evident in a study of the Kidder County tills because the exposed till was probably largely derived from older tills of uniform character which have masked the bedrock.

No major difference in color exists between the tills of the Long Lake, Burnstad, and Streeter advances. The tills are calcareous, light olive gray (5 Y 5/2) when dry and moderate olive brown (5 Y 4/4) when wet. Most of the till has reddish yellow spots, caused by the oxidation of fragments of iron oxide from concretions of the Pierre Shale, and a white mottling, which is due to an irregular concentration of calcium carbonate. In several places in the southwest corner of the county, the till contains cavities filled with crystals of gypsum up to 1/8 inch in length.

Grain Size Analysis

Shepps (1953, p. 35) made size analysis of 75 till samples from Tazewell, early Cary, and late Cary till sheets in several counties of northeastern Ohio. He found that the sand-silt-clay ratios plotted on a triangular diagram were useful in correlating the till sheets. This method was used in analyzing 47 samples of till from Kidder County (Table 1). Histograms were constructed to show the particle size relationships of the tills (Fig. 2). Most plots of the sand-silt-clay ratios fall within a small area on the triangular diagram (Fig. 3). Nearly all the samples that have greater than average percentages of sand have been contaminated with outwash.

Nine out of eleven histograms of the tills show peaks in the fine sand size (Fig. 2). This size grade also has the greatest frequency in the eolian sand which covers much of the county, and it is likely that the eolian material has been incorporated in some of the till samples. Likewise, a high percentage of the particles in eight out of the eleven till histograms falls in the medium silt grade, indicating that they have similar relationships with the peak in the medium silt grade of the histograms of the loess (Fig.6).

An attempt was made to plot the sand and clay percentages on two different isopleth maps (Krumbein and Pettijohn, 1938, p. 201), but only a random distribution of the sand and clay percentages was noted using this technique. Closer spaced sampling, however, might show significant relationships between outcrops of Fox Hills Sandstone, outwash deposits, and the amount of sand in the till. It might be expected that the till west of the contact between the Fox Hills Sandstone and the Pierre Shale would have a higher percentage of sand. However, the difference is not great: 14 samples east of the contact average 31 per cent sand, and 33 samples west of the contact average 33 per cent sand.

Stone Counts

Stone counts have been used to differentiate till sheets by determining differences in provenance. Flint (1955 p. 136-137) made stone counts at 34 localities in South Dakota and found no significant differences in composition of stones in different glacial advances. Pebble counts at 14 till localities in Kidder County showed no major differences in pebble composition (Fig. 4).

Flint (1955, p. 137) indicates that the true percentage of shale pebbles is difficult to determine because the shale pebbles disintegrate easily. The coarse sand fractions separated during the sieving were saved and the percentages of the shale fragments contained therein were determined, but no significant differences between the tills were found. It might be expected that the till east of the contact of the Fox Hills Sandstone and the Pierre Shale in the county would have a higher percentage of shale fragments. However, shale particles average 27 per cent of the coarse fraction in samples from east of the contact, whereas those collected from west of the contact average 31 per cent of shale in coarse sand fraction.

The difference in per cent of shale might be attributed to the larger amount of outwash incorporated in the till east of the contact.

Leaching

The depth of leaching of carbonates in tills has been used by some workers for determination of the relative age of tills. Till of Mankato Age in South Dakota was found to have a mean depth of leaching of 23 inches (Flint, 1955, p. 79). The writers used dilute hydrochloric acid to test the upper few feet of till in Kidder County, but found that the leaching of calcium carbonate from this part of the till was negligible. However, white weathering calcium carbonate is commonly concentrated in horizontal zones in some occurrences of stratified gravel and sand. These layers of calcium carbonate might be due to the partial leaching of calcite from some of the limestone and dolostone boulders in the till and redeposition of calcium carbonate along permeable zones in the drift. Secondary accumulation of carbonate commonly results because of lower rainfall and high evaporation characteristics of climate of the Great Plains.

Boulders

Boulders appear to be more abundant in end moraines than in either dead-ice or ground moraine. The number of boulders observed on the surface of end moraine increases proportionately with the slope. The boulders on the surface are in greater abundance on the distal slopes of end moraines than on the proximal slopes because the former are generally steeper and erosion is deeper there. Thus, a residual concentration of boulders occurs as the fine-grained material is carried away by surface water. The maximum size of the boulders is 10 feet in diameter, but averages 2½ feet.

Boulders are more numerous at the front of the maximum advance of the ice, the englacial position, rather than in the deposits which occur at the base of the ice in the ground moraine due to attrition during transport. Hence, end moraine has a larger percentage of boulders than does ground moraine.

Large boulders made of the local bedrock were absent from the drift of Kidder County. The source of part of the material in the tills of the county is the bedrock which was originally exposed in counties to the north and east and from the clay-rich till which masks much of the state to the east. Moreover, the local bedrock is poorly consolidated, and hence, blocks derived from the bedrock would be rapidly reduced in size after dislodgement.

An anastomosing concentration of boulders occurs in the stagnation moraine in Sections 34 and 35, T. 143 N., R. 74 W. The boulders are present on the surface and within the till. Conspicuous ridges are formed because the boulder concentrations are more resistant to erosion than the adjacent till with fewer boulders. These ridges are sinuous when viewed from the ground, as well as on air photographs, and range from 20 to 30 feet in height and up to 60 feet in width. The boulders range from 1 to 3 feet in diameter. This curious arrangement of boulders might be a crevasse filling or local ice-crack feature which formed in dead-ice moraine.

GLACIAL MARKINGS

A number of boulders in the till have polished and faceted surfaces. Flint (1955, p. 56) suggests that polished surfaces are formed by abrasion from clay near the base of the glacier and that the striations were made contemporaneously by fragments of larger size. The faceted surfaces occur mainly on dolostone boulders, whereas they are absent from the boulders made of coarse-grained igneous rock. These boulders and cobbles have been planed as moving ice held them firmly against other boulders or the bedrock. Further, most of the planed surfaces show striations.

Dolostone cobbles and pebbles were also found to bear striations, which are generally less than 1 cm. in depth and occur in closely spaced intervals. The striation patterns are generally oriented parallel to the long axis of the fragment.

TOPOGRAPHIC EXPRESSION OF GLACIAL DRIFT

End Moraine

An end moraine is a ridgelike accumulation of drift deposited by an ice sheet at its margin. The long axis of the ridge is transverse to the direction of glacial movement. An excellent discussion of end moraine occurs in Flint's treatment of the Pleistocene geology of South Dakota (1955, p. 111-117).

According to him, the initial form depends "on the amount of rock material contained in the glacier and its vertical distribution within the ice, the rate of flow of the ice, rate of wastage in the terminal zone, and the relative amount of meltwater operative in the terminal zone." Thwaites (1957, p. 40) describes their range in form as follows: "In detail there is every graduation between simple smooth ridges, for the most part with very gentle slopes, to the most amazing complex aggregations of knobs and ridges interspersed with enclosed kettles." He further states that they are not common to all ice margins, but only where the ice has remained in place long enough to build up a deposit.

The slope of the end moraine is dependent upon the lithology of the till. Till with a high clay content will commonly have gentle slopes and few kettles, while a permeable, sandy to gravelly till will have many kettles and steep slopes.

The mapping of moraines in Kidder County was complicated by the difficulty in distinguishing end moraines and dead-ice moraine from bedrock highs covered with till.

Where viewed from a distance, these bedrock highs have the appearance of end moraines. They have previously been indicated as such on the Glacial Map of the United States East of the Rocky Mountains (Flint, et al., 1959). However, this study has revealed that they are areas of relatively high bedrock covered with a thin veneer of till and these areas have been distinguished on the map (Plate 1). It is likely that the bedrock highs acted as temporary impediments to the advancing ice and also influenced the local directions of ice movements. Hence, the distribution of end moraines in the county has been closely controlled by the position of these bedrock highs. Moreover, other workers have stated that preglacial topography was a controlling factor in the movement of ice lobes (Horberg and Anderson, 1956, p. 108).

Dead-ice Moraine

Dead-ice moraine is formed by the isolation and melting in place of debris-covered ice. As ablation takes place, the till and some reworked material collapse at the margin of the block, thus insulating the underlying ice and slowing its rate of melting. Differential melting of the isolated blocks of ice occurs and the thicker ice, which contains more material, forms knobs of moraine, while the thinner ice, with less debris, leaves an irregularly shaped depression floored by deposits of till.

Kidder County, in comparison to some other glaciated areas in the northern mid-continent, has relatively large areas of dead-ice moraine scattered over the numerous bedrock highs of the Coteau. This is the type of deposit that is characteristic of the Coteau in North Dakota and is what one would expect in this higher area of isolated buttes and mesas where the free flow of the westward moving lobes of ice was interrupted. Clearly, an irregular and deeply dissected bedrock surface retards the smooth flow of glacial ice and causes stagnation and separation of the lobe into blocks.

There has long been controversy as to whether or not ice could become stagnant during deglaciation (Charlesworth, 1957, p. 1147). Flint (1942, p. 121-123) and Sharp (1951, p. 109), however, are among those who cite examples of existing glaciers with stagnant ice. Some authors have distinguished between "normal" recession, during which a glacier maintains a distinct receding terminus while flow continues actively, and stagnation and separation, which are characterized by widespread thinning. These two modes of shrinkage are gradational and a single glacier can exhibit both in different parts at the same time (Flint, 1957, p. 33).

Flint (1955, p. 115) states that a slow advance or retreat of the ice across a particular area would build up a thick deposit of till in that area and the deposit would assume the form of a ridge, i. e., an end or recessional moraine. If the ice should for some reason become stagnant, it would no longer build ridges of till because drift would be let down when the ice melted and the resulting deposits would have no apparent trend. The drift of the stagnant ice comprises dead-ice moraine. Moreover, Flint (1957, p. 152) states that in some cases a peripheral belt of glacier ice many miles in width becomes stagnant and separates into isolated masses, and stratified drift deposited upon and between such masses creates complexes of kettles.

Thwaites has summarized the sequence of events which leads to stagnation. The thickness of a glacier decreases when the snow supply becomes less. Reduction in thickness then decreases the plasticity of the deeper ice and the glacier moves slower with passage of time. Eventually, there is too little force to overcome internal resistance to flow and stagnation results (Thwaites, 1956, p. 15, 17). Thwaites concludes that as the glacier melts back it thins and that the stagnation of an entire glacier was common during the Pleistocene Epoch. Flint (1957, p. 163) concurs in stating that there is no reason why an extensive ice sheet should not thin to a point of stagnation during the late phases of its shrinkage, but he adds that evidence supporting this concept is lacking.

Lemke and Colton (1958, p. 56) state that the Max moraine, which forms the surface deposits of much of the Coteau du Missouri, northwest of Kidder County, is generally characterized by a very hummocky moraine or "dead-ice" moraine, rather than being formed of distinct end moraines. They suggest that the stagnation features composing the Max moraine might represent more than one major ice advance.

Lemke and Colton (1958, Fig. 5) show stagnation features extending across North Dakota all along the Coteau to the South Dakota line. In South Dakota, adjacent to the stagnation moraine, Flint (1955, Plate 1) shows ground moraine associated with discontinuous belts of end moraine.

Ground Moraine

Ground moraine is a deposit of glacial drift which has low relief generally less than 20 feet, and has none of the transverse linear ridges common to both end and recessional moraine. In North Dakota, it produces a type of topography characterized as swell and swale, which describes the gently sloping knolls and meadowland commonly occurring just behind certain end moraines.

Thwaites (1957, p. 41) comments on its genesis as follows: "It was once thought that ground moraine was mainly a deposit of till under the bottom of moving ice. If this were true, it would be impossible to explain what became of the debris in the ice when it melted." Thwaites accounts for this by concluding that the surficial part of ground moraine has accumulated when the ice melted. Therefore, the vast deposits of dead-ice moraine in North Dakota might well rest upon ground moraine.

STRATIFIED DRIFT

Classes

Stratified drift is derived from till which has been reworked by running water causing the coarser particles of silt, sand, and gravel to become bedded and most of the clay-size particles to be carried away in suspension. According to Flint (1955, p. 63), stratified drift can be subdivided into two types which are ice-free deposits and ice-contact deposits. The ice-free deposits can be further subdivided into outwash and ponded water deposits. In Kidder County, there are vast deposits of outwash, some of which were deposited on ice. Subsequent melting of the ice resulted in areas of collapsed outwash.

The ice-contact deposits are formed next to the ice by streams flowing in cracks or between the ice and the valley wall, whereas the outwash sediments are deposited beyond the glacial margin by streams issuing from the glacier.

Ice-contact Deposits

The commonest kinds of ice-contact deposits are collapsed outwash deposits, eskers, and kames. An esker is a long sinuous ridge composed of stratified material which has been deposited below or within the glacial ice. It shows by its long serpent-shaped ridge that it was built by a stream which was in contact with glacier ice. Probably the most common origin of eskers is in tunnels at the basal part of the ice of a glacier in a stagnant or near stagnant phase. The downward percolation of meltwater from the surface through crevasses forms tunnels in the basal zone of the glacier. Flint (1957, p. 157) has written of the tunnels as follows: "It is unlikely that tunnels could easily form, or, once formed, stay open unless the ice that enclosed them was nearly motionless." The deposits of eskers generally are cross-bedded and poorly stratified mixtures of sand and gravel. According to Flint (1957, p. 157), "Unless the whole of the esker, after completion, was protected by enclosing ice, it is not easy to account for its preservation from destruction by proglacial stream erosion or from burial beneath outwash."

One of the commonest ice-contact deposits in the drift of Kidder County is the kame, a cone-shaped mixture of sand, gravel, and till. Kames originate through the accumulation of sediments in depressions or crevasses. Wasting of the ice causes the enclosed deposits to be let down as relatively conical or irregular-shaped mounds. Because the predominate material of kames and eskers is sand and gravel, these deposits are economically important as construction materials.

Glacial Lake Deposits

Lake deposits are commonly composed of fine-grained laminated material and indicate areas where ponded water collected debris from streams. The lake deposits also contain loess near their margins where tree-stands acted as wind breaks. The sediment contains light brown laminae alternating with dark brown laminae. The alternating layers of clay size material are termed rhythmites.

The Long Lake trough contains a sequence of laminated deposits which probably represent the ponded episode of the ancestral Cannonball River after it was dammed by an ice lobe. Other occurrences of laminated drift are restricted to a few exposures in the dead-ice moraine where small temporary lakes existed. Exposures of varved sediments are rare in the county.

NON-GLACIAL DEPOSITS

Alluvium

Alluvium has been deposited in most of the major valleys and kettle lakes during post-glacial time, but the topographic features of the area show few effects of post-glacial erosion. The drainage is not integrated. Small centripetal drainage patterns exist in the kettles and broader depressions. Consequently, a small amount of alluvium has been deposited in the kettles. Glauber's salt is concentrated at the surface as a white powdery residue where the lakes have dried up. The powdery residue, which occurs as grains of sand size and smaller, is often dispersed over the surrounding countryside by strong winds. Surface runoff has washed a small amount of alluvium to the gully bottoms in some of the bedrock highs and moraines.

Colluvium

Colluvium is an unsorted deposit consisting of material ranging in size from clay to boulders, which accumulates on hillsides and in valley bottoms by down-slope movement of weathered rock or unconsolidated debris. It commonly occurs in the gullies of Recent Age, which occur throughout the high areas of end moraine and in the bedrock highs.

Eolian Features

The most recent deposition in the area is that of silt sized material transported by the wind. The silt deposits are widespread over the outwash plain and are incohesive and commonly dry in the summer and fall. Thus, it is relatively easy for even a moderate wind to move the surface material about over the outwash plain and adjacent areas. Many of the ditches and small depressions have recently been filled with wind-blown silt, and on windy days, large clouds of dust drift across the cultivated areas. An area of eolian deposits occurs along the east side of Horsehead Lake (Plate 1). Although this area does not possess well developed dunes, gently rolling topography and deposits of unconsolidated silt and fine-grained, well rounded quartz sand indicate its eolian origin. A dark gray to medium black silty soil layer up to 6 inches thick covers the surface in this area. Closer to Horsehead Lake, the silt is mixed with clay and, when dry, the surface is covered with a hard alkaline crust. The western part of this eolian sand area also contains clay mixed with sand.

Deflation has been a dominant process in local areas such as Horsehead Lake and Long Lake, where large volumes of fine-grained sediments are swept away by the wind. Some boulders which rest on the crests of ridges have been partly reburied by wind-blown silt trapped by the prairie grasses. Deflation has also caused a general leveling of the surface of the outwash plain.

Sand Dunes

A large area of fixed sand dunes occurs in the Dawson State Game Refuge south of Dawson, North Dakota. This area contains numerous small longitudinal sand dunes which trend northwest and range from 5 to 35 feet in height. The sand consists chiefly of medium brown, fine-grained quartz. Shrubs and prairie grasses have fixed most of the dunes, but several blowouts have occurred within the area. The lee slope of the dunes faces southeast; hence, the wind direction at the time they were active was from the northwest. South of Lake Etta, an even larger area has been covered by eolian sand, but dunes are absent. The sand is spread over the outwash plain of the Long Lake trench and covers some 16 square miles of outwash. Its surface is characterized by gentle swells which rise toward the higher end moraines 4 miles south of Lake Etta.

In the vicinity of Tappen, North Dakota much of the outwash as well as part of the end moraine to the east and south are covered by a thin veneer of eolian sand of Recent Age. A dune area occurs southeast of Tappen in the east-central part of T. 139 N., R. 71 W. The maximum relief in the dunes is 15 feet, but the average is about 6 feet. The dunes trend southeast and are composed of very fine-grained dark brown sand and silt. Quartz is the dominant mineral constituent in the sand.

The position of the dune areas on the southeast side of major areas of outwash, and the fact that the wind direction at the time of their deposition was from the northwest, suggest that much of the sand must have been derived from the outwash plain.

Loess

Loess is a wind-blown deposit which is dominantly composed of silt size material. Loess has been noted in several exposures in the county. By far, the majority of the loess in the county is post-glacial in age. A deposit from ½ to 3 feet thick of loess covers much of the outwash and till in the south half of the county. It contains very fine-grained sand and silt, as do the fixed sand dunes south of Lake Etta in the Dawson State Game Refuge, and is genetically the same as loess (Fig. 5a, 5b, and 5c). It is generally dark brown, non-bedded with much organic material. Similar deposits of sand were found above the spruce wood in the Twin Buttes end moraine, which was dated by radio carbon methods' at 11,480 years B. P. (Moir, 1958, p. 109-110).

Yellow loess was observed in these four localities in the county:

1. Roadcut 6½ miles north of Tappen, a half-mile south of the northwest corner of Sec. 2, T. 140 N., R. 71 W.; 3 feet of loess is overlain by a half-foot of gravelly till.
2. Near South shore of Lake Isabel, 4 miles south of Dawson, in the SE ¼, SW ¼, Sec. 34, T. 139 N., R. 72 W.; 7 feet of loess-like material overlays laminated lake clay; sample C1-7, histogram Fig. 6b.
3. Roadcut 2 miles east of Alkali Lake, a half-mile south of the northeast corner of Sec. 12, T. 137 N., R. 70 W.; 20 feet of loess interbedded with outwash; sample C1-52; histogram Fig. 6c.
4. Roadcut 8½ miles south of Tappen, 0.3 miles north of the southwest corner of Sec. 22, T. 138 N., R. 71 W.; loess separates the two tills of the Long Lake and Burnstad advances, respectively.

In conclusion, the distribution of loess in Kidder County is restricted to a few isolated outcrops of till and outwash. Whether or not the loess is spread as sheets between the different drift sheets is not clear because of the paucity of good exposures. The present work indicates there are no widespread loess deposits in the county other than those of post-glacial age.

BEDROCK HIGHS AND ICE-SHOVE DEFORMATION

Bedrock Highs

The bedrock high in T. 144 N., R. 73 W. has an elevation of 2,294 feet and is the most prominent landform in northern Kidder County. Bedrock was not observed on the margins nor in the center, but auger holes in Sec. 2, T. 144 N., R. 73 W. showed 2 feet of clay-rich till over bedrock consisting of poorly compacted fine-grained brown sandstone. According to Hansen (1956), the Tongue River Formation is present beneath the drift at this locality. Because the sandstone is poorly consolidated, good outcrops of this formation are unlikely to be found. The topography of this bedrock high consists of linear, drift-covered ridges which have slopes of up to 30 degrees. The gullies cut in it are V-shaped and form a well defined dendritic drainage pattern which probably was formed by preglacial streams. The trend of the bedrock high crosses the trend of the Woodhouse Lake Loop. The long axis of the bedrock high forms an angle of 45 degrees with the west segment of the end moraine and 27 degrees with the east segment.

At least 10 exposures of bedrock are present in roadcuts through the bedrock high in T. 143 N., Rs. 73 and 74 W. A maximum of 30 feet of till was found above the bedrock. Moreover, the preglacial surface was dissected by streams and the dendritic pattern has persisted.

The bedrock high in T. 143 N., Rs. 72 and 73 W. is divided into two parts by a band of outwash. A dendritic drainage pattern with V-shaped valleys and two exposures of bedrock provide evidence that it is a bedrock high covered with a thin veneer of till.

Smaller bedrock hills occur throughout the stagnation moraine. These smaller landforms do not resemble end moraines so well as the larger bedrock highs. A small till-covered bedrock hill rises about 100 feet above the surrounding stagnation moraine in SW ¼ Sec. 26, T. 144 N., R. 73 W.

Boulders up to 6 feet in diameter, but averaging about 2½ feet in diameter, rest on the surface of the bedrock highs. Most of these boulders are granitic and basic igneous rocks; the remainder are mostly dolostone. It is evident, then, that the ice was mobile enough to cover the bedrock highs. The till was deposited on the bedrock surface when the ice melted, but the thickness of the drift indicates that the ice sheet must have been thin over the higher bedrock areas.

Sibley Buttes

The Sibley Buttes are a series of relatively high hills located about 9 miles north-northeast of Steele, North Dakota. A problem is involved in deciphering the history of the Buttes in order to account for the steeply dipping beds of Fox Hills Sandstone which occur at their crests. The top of the Buttes is approximately 275 feet higher than the glacial drift to the northeast and it rises about 200 feet above the outwash plain to the southwest. Approximately 15 strikes and dips were recorded on the sandstone which crops out near the tops of the ridges at about the same elevation.

The strike of the sandstone beds cropping out at the crests of the Sibley Buttes ranges from N. 14 W. to N. 84 W., and the dip ranges from 18 to 90 degrees to the northeast. The regional dip of the Fox Hills Sandstone in this area is 2 to 3 degrees to the northwest. The strike of the sandstone ridges at the top of the Buttes conforms to the general trend of the hills, and the individual hogbacks are mappable throughout them. Some of the sandstone ridges are sinuous and the ridge crests slope gently to the northeast. Further, large blocks of sandstone, ranging up to 6 feet in diameter, are scattered about the tops of the Buttes and have apparently been shoved or displaced to the southwest. These blocks are arranged in lines which have arcuate trends. The strike of the lines of displaced blocks is generally due south, a trend which is not parallel to the strike of the Buttes, and, hence, the arrangement of the blocks is not related to bedrock structure. Any solution to the problem of deformed strata in the Sibley Buttes must take into account that the rows of sandstone blocks have been arranged into arcuate trends and that these blocks have moderate to steep dips to the northeast.

The Sibley Buttes, prior to the initial glaciation of Kidder County, were a series of discontinuous buttes, probably somewhat like those found in the present badlands of western North Dakota. A test hole of the United States Geological Survey, drilled 1½ miles northeast of the Sibley Buttes, indicates that the bedrock occurs 520 feet below the top of the Buttes.

The origin of the steeply dipping beds at the top of the Sibley Buttes might be explained by ice-shove deformation from an ice lobe advancing from the northeast.

Ice-shove Deformation

The frictional drag of thick glacier ice passing over weak underlying strata can produce displacement and folding in beds near the contact (Flint, 1957, p. 90). Ice-shove deformation has been reported in several places, such as South Dakota (Flint, 1955, p. 63), Kansas (Wood, 1959, p. 304), and Iowa (Lamerson, 1957, p. 546).

Northern Kidder County furnishes abundant evidence of ice shove, and the discussion which follows summarizes the evidence indicated by a study of the outcrops there. The attitude of 10 of the 13 exposures of bedrock was determined in this area. The dip of the beds in these outcrops ranges from 9 degrees to vertical, with most of the outcrops showing beds which are steeply dipping. The strike of the bedrock can change considerably within a short distance, i. e., in Sec. 17, T. 143 N., R. 73 W., the strike changes from N. 32 degrees

E. to N. 12 degrees W. within a distance of 200 feet. Generally, the strata of Upper Cretaceous and Lower Tertiary Age of North Dakota have only a slight dip.

Detailed studies of these outcrops would be necessary to determine more precisely the nature of the deformation caused by ice shove. However, it is evident that the irregularities of the bedrock exposed 0.3 mile north of the southwest corner of Sec. 13, T. 143 N., R. 74 W. were caused by ice shove. The outcrop shows 3 feet of till above 5 feet of the Tongue River Formation. An involution of till occurs in the deformed bedrock. The contact between the till and bedrock is irregular, and the bedding of the bedrock is distorted. It is likely that the involution had its origin in the following way. The soft sandstone beneath the ice was plastically deformed where it became lubricated with water and was under pressure of the weight of ice above. Consequently, the till became incorporated into the sand beneath the ice.

The Tongue River Formation is deformed in an outcrop 0.2 mile north of the southeast corner of Sec. 7, T. 143 N., R. 73 W. Here the beds are faulted and range in attitude from nearly horizontal to vertical.

At other places in North Dakota, deformed bedrock has been attributed to either deep-seated forces or to ice shove. Townsend (1950) concluded that the Fort Union Formation near Lignite, North Dakota, is intensely folded and faulted due to deep-seated forces. This area is also covered by a mantle of drift.

The most prominent structures in the bedrock due to ice shove are found in the Sibley Buttes.

Frozen-ground Phenomena

A periglacial environment often gives rise to frozen-ground phenomena by alternate freezing and thawing. Irregularly contorted structures, known as involutions, occur at depths of less than 13 feet in some Pleistocene sediments (Flint, 1957, p. 200).

An involution having a boot-shaped form (**Brodelboden**) occurs 0.2 mile north of the southeast corner of Sec. 27, T. 143 N., R. 72 W. A gravelly till overlies cross-bedded sand and gravel in this outcrop. An involution of the gravelly till occurs in the outwash. Further, in this exposure the contact between the till and the outwash is irregular. The involution occurs at a depth of 2 feet at the contact between the till and the outwash.

Horberg (1951, p. 11) states that involutions are believed to be the result of plastic deformation, which is produced by differential freezing and thawing, and growth and melting of masses of ground-ice above perennially frozen ground. He describes boot-shaped forms, or **Brodelboden,** caused by differential thawing and freezing in Lake Agassiz sediments 6 miles south of Edinburg, North Dakota. Sharp (1942), Denny (1936), Schafer (1949), and Flint (1955) also describe similar structures which are due to differential freezing and thawing at other localities in North America.

STRATIGRAPHY OF THE WISCONSIN DEPOSITS

General Statement

The most workable basis for distinguishing the deposits of different age of the separate ice advances in Kidder County is to map the trends or distribution of the different drifts. The arcuate ridges of the end moraines are nearly continuous for each of the three major ice advances. The end moraines represent the maximum advance of each ice sheet and distinguish the till associated with each advance from preceding and subsequent advances. Hence, the contact between different till sheets is drawn along the distal side of the end moraines marking the maximum advance.

Tills from different glacial advances in the end moraines of south-central North Dakota are difficult to differentiate by lithology alone. Little difference exists between tills of the Long Lake, Burnstad, and Streeter advances. If the major direction of glacial flow in the different substages had varied, the till lithologies might have been different. However, the major glacial movements were southwest and west, passing over nearly 200 miles of shale.

In northwestern North Dakota, where the ice approached from more than one direction, Howard (1956) outlined the contact between two different tills by using stone counts. Stone counts were made in more than 60 places in Kidder County, but only subtle differences in the tills of the different drift sheets were noted. Nevertheless, it is clear from the distribution of the three end moraines, the Long Lake advance marked by the Long Lake moraine, the Burnstad advance which deposited the Twin Buttes moraine, and the Streeter advance terminated by the Lake Williams, McPhail Buttes, Crystal Springs, and Lake George loops, that two separate drifts lay superposed along the eastern margin of the county and that at least three are present on the western edge where the till of the Long Lake moraine rests on older drift.

All the surficial glacial deposits in Kidder County are referred to the Wisconsin Stage (Lemke and Colton, 1958, p. 41).

Exposures of Two Tills

The two tills were discovered in three localities in Kidder County. The relationship between these tills and the substages of the Wisconsin is not clear.

In a roadcut 8½ miles south of Tappen, North Dakota, 0.3 mile north of the southwest corner of Section 22, T. 138 N., R. 71 W., the following section of drift was measured.

	Feet
6. Sand, fine-grained, dark brown, with silt matrix.	1.9
5. Till, pale olive (5 Y 6/3-dry) with reddish orange iron oxide spots up to 5 mm. in diameter; 1 ft. of calcium carbonate concentrated 1.6 ft. below the top; sample C1-37-E; histogram-Fig. 2F (probably equivalent to the till of the Twin Buttes end moraine.)	3.8

4. Loess, pale yellow (5 Y 7/4 dry) with inconspicuous vertical joining, containing tube-shaped ferruginous concentrations up to 2 mm. in diameter; sample C1-37-d; histogram-Fig. 6.	0.2-0.8
3. Gravel with a few boulders up to 1 ft. in diameter.	.2
2. Till, pale olive (5 Y 6/3-dry), with reddish brown iron oxide spots up to 5 mm. in diemeter; 0.1 ft. of calcium carbonate concentrated at the top of the unit; well compacted; sample C1-37-B; histogram-Fig. 2; (probably equivalent to till of the Long Lake drift.)	5.0
Concealed interval	7.0
1. Till, pale yellow (5 Y 7/3 dry), with reddish brown spots of iron oxide, like unit 2 above, with base concealed.	2.0
Total	20.7

This section assumes considerable importance if, indeed, the two tills represent two separate ice advances, the Long Lake and Burnstad advances, respectively The presence of the loess between the two till deposits possibly indicates a temporary withdrawal of the ice from the area before the upper till was deposited. Flint (1955, p. 39, 97) noted tube-shaped ferruginous concretions in many of the South Dakota loess sheets. Lemke and Kaye (1958, p. 94) found a lime concentration associated with boulders between two tills in north-central North Dakota. An alternative and more conservative hypothesis for the origin of the two tills would be to consider them as deposits of two local advances of the ice lobe which deposited the Twin Buttes end moraine. This might mean the loess deposit represents only a short time period, rather than a significant break between two major ice advances.

Another exposure in which two tills were found is located 13 miles south of Dawson, 0.3 mile north of the southeast corner of Section 16, T. 137 N., R. 72 W., on either side of North Dakota State Highway 3.

	Feet
3. Till, pale yellow (5 Y 7/3 dry), reddish brown spots of iron oxide, containing boulders of Fox Hills Sandstone and more pebbles than the unit below; sample C1-10-C; histogram Fig. 2 (Long Lake advance).	3.0-8.0
Unconformity	
2. Till, pale yellow (5 Y 7/4-dry) plastic when wet, dense and compact when dry; reddish orange stains of iron oxide and coatings of manganese oxide on the faces of small, irregular, closely spaced joints; samples C1-10-A (1 ft. below top) and C1-10-B (6 ft. below top); histogram-Fig. 2.	10.0
1. Till, similar to unit 2 but gray in color; probably the unoxidized equivalent of unit 2 above.	5.0

The till of unit 2 in the above section is the only deposit in the county that differs conspicuously from the tills of either the Long Lake, Burnstad or Streeter advances. Moreover, it is superficially similar to till of Iowan or Tazewell age in north-central North Dakota, which contains iron and maganese oxide coatings on small irregular joint faces (Lemke and Kaye, 1958, p. 95). Further, the presence of these oxides has been noted on the surfaces of joints of Iowan till in South Dakota (Flint, 1955, p. 35).

A third exposure in northern Kidder County within the dead-ice moraine contains two tills. The tills crop out 0.3 mile east of the southwest corner of Section 25, T. 144 N., R. 73 W. The upper 5 feet of the exposure contains light olive brown (5 Y 5/6-dry) colored till which is calcareous. It overlies about 5 feet of moderate olive brown colored till, of which the upper 3 feet is leached of calcium carbonate. The color of the lower till more closely resembles the till of the Long Lake advance, whereas the upper till is similar to the widespread deposits of dead-ice moraine of the Streeter advance which are spread over the northern tier of townships in the county. Admittedly, this is a subtle differentiation, but the non-calcareous lower till is testimony to two separate advances which were separated by a time span long enough to leach calcium carbonate from 3 feet of the lower till.

Regional Correlation

Correlation of the deposits poses a problem because of new concepts developed during the Kidder County study.

Lemke and Colton (1958, Fig. 3) correlate the Long Lake drift with the Burnstad drift and with the A-1 advance of Flint (1955, Plate 1, p. 119). It appears that the Twin Buttes moraine, herein referred to the Burnstad drift, overlaps the Long Lake drift in the south-central portion of Kidder County. If this hypothesis is true, the relationships between the Long Lake drift and other drifts to the south and east are probably obscured by the Burnstad drift, and tentative correlations between the respective deposits become more doubtful than ever. For this reason, no attempt is made herein to correlate drifts older than the Burnstad.

Long Lake Drift

General Statement

The Long Lake drift (Plate 1) consists chiefly of end moraine, and ground moraine. Small areas of outwash believed to be derived from the Long Lake drift cannot be mapped separately from younger outwash. Other glacial features associated with the Long Lake drift include eskers, kames, outwash channels, kettle chains, and a glacial lake deposit.

Outcrops of bedrock within the Long Lake drift are all Fox Hills Sandstone, and the bedrock highs are believed to be referrable to the same formation.

Dune sand deposits within the area of the Long Lake drift are post-glacial and were derived chiefly from younger outwash.

Occurrence

The Long Lake drift is bordered on the west by older drift, on the southeast by the Twin Buttes end moraine (Burnstad drift), and on the east and north by the various areas of end moraine and dead-ice moraine of the Streeter drift.

The Long Lake end moraine consists of two broad loops in southwestern and west-central Kidder County. East of the Long Lake end moraine and adjacent ground moraine, much of the Long Lake drift is buried by younger outwash.

Lithology

The moraines of the Long Lake drift are composed of stony clay till. The outwash areas and the kames and eskers are composed of silts, sands, and gravels, with lenses of till. The outwash channels and kettle chains are floored with sands and gravels and recent alluvium over till. The glacial lake deposit consists of laminated clays over till.

Thickness

The thickness of the varous landforms of the Long Lake drift varies widely. Outcrops of Fox Hills Sandstone are fairly common in the areas of the bedrock highs where the tills are so thin that the integrated preglacial drainage patterns have persisted and are evident on aerial photographs.

Topographic Expression

End Moraine

The Long Lake end moraine (Plate 1) occurs partly in Logan, Emmons, Burleigh, and Kidder Counties, and is breached by the valley occupied by Long Lake near its center, which contains a tongue of outwash derived from the Streeter advance. The topography of the southern loop consists of irregular knolls and kettles which have gentle slopes and rise higher than the adjacent ground moraine and outwash. Aerial photographs show that the thin drift has not obliterated the drainage pattern of the preglacial bedrock surface. A large percentage of the depressions in this moraine drain into the Long Lake trench, but there are a few large undrained depressions up to 300 yards across. The relief in the maze of knolls and smoothly rounded depressions is much less than in either the end moraine or dead-ice moraine of the Burnstad and Streeter advances. This shows that the physical appearance of an end moraine is not only determined by its mode of deposition and the character of its drift, but also by the length of time it has been exposed to weathering and erosion. There is little doubt that the Long Lake moraine is older than the Burnstad and Streeter drift on the eastern margin of the county.

Ground Moraine near Steele

Ground moraine occurs in the vicinity of Steele, North Dakota. North of Steele, the topography is relatively flat, with the relief ranging from 10 to 15 feet, while to the south, the relief is more pronounced. There is a gentle slope from both directions toward an extensive kettle chain in the south portion of T. 140 N., R. 73 W.

The eastern part of the area is underlain by areas of relatively higher bedrock which is covered with a thin veneer of till. Fox Hills Sandstone of Upper Cretaceous age is exposed in Section 35, T. 139 N., R. 73 W. Bedrock also occurs at shallow depth beneath the till about 6 miles southwest of Steele in Sections 10, 11, 16, 17, 20, and 21, T. 138 N., R. 74 W. Kames are scattered in three localities of this ground moraine: Section 18, T. 139 N., R. 73 W., and Section 21, T. 140 N., R. 73 W. A large meltwater channel that trends east is located in the northern part of T. 140 N., R. 73 W. The channel is floored with gravel and alluvium of Recent age.

The northwest trending outwash deposit in the southwest corner of T. 139 N., R. 73 W., is approximately 50 feet below the surrounding area on the east and west. Its eastern slope is scarred by numerous gulleys cut by post-glacial streams which flowed into the valley. The contact of the ground moraine with the extensive outwash area on its eastern margin is subjective. Locally, the outwash overlaps the ground moraine and, hence, is younger.

Ground Moraine near Long Lake

Ground moraine flanks outwash on the north and south sides of Long Lake. The moraine was deposited on the proximal side of the south loop of the Long Lake end moraine as the ice melted back to the northeast along the Long Lake trench. The till is characteristically sandy and pebbly and is light olive gray to tan colored. The ground moraine has a low undulating surface which rises in elevation toward the end moraine and descends gradually to the level of the outwash plain immediately adjacent to Long Lake. This ground moraine was deposited at about the same time that the ground moraine near Steele was laid down, as the middle lobe of the Long Lake advance melted back.

STRATIFIED DRIFT

Outwash

Only small areas of outwash are referrable to the Long Lake drift (Plate 1). Outwash with low to moderate relief occurs in T. 139 N., R. 74 W. Cross-bedding in gravel pits indicates that currents flowed to the southwest at the time the gravels were deposited. A nearby source of gravel to the northeast is indicated by the direction of current flow and by the coarseness of the gravel.

Kames

In 1958-1959, kames were sought as sources of material for highway construction in North Dakota and certain of them might yield material for this purpose in the future.

A well developed kame occurs in the central part of the county in Section 10, T. 140 N., R. 72 W. Much of its sand and gravel has been removed for road construction. The sediments show stratification and lenses of fine to medium-grained sand are present, as well as beds of tilted sediments near the outer margin. The tilting and faulting occurred when the surrounding ice melted.

The irregular hill in Sec. 7, T. 140 N., R. 74 W., has the external characteristics of a kame. Augering showed that the upper part of the deposit consisted of 8 to 10 inches of till and the lower part was coarse sand with a few pebbles. It is likely to yield considerable quantities of sand and gravel and is worth further prospecting.

Four small kames, located in Sec. 18, T. 139 N., R. 73 W., have been extensively worked for gravel. A large kame in Sec. 7, T. 140 N., R. 73 W., provided much gravel for the surfacing of N. Dak. Highway 3 in 1959. This deposit is mostly sand with lenses of gravel.

Eskers

Among prominent eskers in central Kidder County is a large northeast trending esker in Section 33, T. 140 N., R. 72 W. This esker has been mined for gravel and the original structures have been destroyed.

The sinuous ridge located in Section 6 and 7, T. 141 N., R. 73 W., is the best example of an esker in central Kidder County. A section through the esker is exposed in a roadcut in Section 6, T. 141 N., R. 73 W., where 6 feet of gravel and sand with rounded shale pebbles is underlain by approximately 14 feet of clay-rich till. The esker was formed at the border of the ice lobe near the margin of the Sibley Buttes moraine and has been partly buried by outwash of the Streeter advance.

Lake Deposits

Some evidence indicates the presence of a glacial lake, herein termed Lake Steele, near Steele, North Dakota, in T. 139 N., R. 73 W.

Several auger holes were made in this vicinity to determine the character of the glacial lake deposits. All of the holes showed yellow-brown colored clay and silt. Good exposures of laminated silts were found in several pits in Steele and a maximum thickness of 7 feet of silt was observed one block west of the Steele high school.

Other laminated deposits of lacustrine origin were found in cuts on the west margin of Lake Isabel in Section 34, T. 139 N., R. 72 W., where a section of more than 3 feet of gray laminated silt and clay was observed. Overlying the laminated silt and clay is a bed of dirty, coarse sand and gravel two feet thick.

Because Lake Isabel is on the floor of a southwest trending spillway, it is not unlikely that this area was temporarily dammed as lobes of ice advanced southwest down the main valley of the Long Lake trough.

In South Dakota, Flint (1955, p. 123) states that "it is probable that other lakes — perhaps many others existed, held between glaciers and the slopes of the Coteau, and that their sediments have been either buried beneath till during readvances of the glacier margins or washed away by local runoff after the lakes were drained." This could have happened in Kidder County as well.

Relation to Other Drifts

The lower boundary relationships of the Long Lake drift are unknown.

The Long Lake drift is overlain by the Burnstad drift on the southeast and by the Streeter drift to the east and north.

Tentative Correlation

The Long Lake drift cannot now be correlated with any regional trends.

Burnstad Drift

General Statement

The Burnstad drift (Plate 1) consists chiefly of the Twin Buttes end moraine and associated dead-ice moraine. Within the limits of the dead-ice moraine in T. 137 N., R. 71 W., a small but conspicuous loop of end moraine is mapped in this report as the Fresh Lake moraine.

A few outcrops of Fox Hills Sandstone occur within the limits of the Burnstad drift in the southwest corner of T. 138 N., R. 70 W., and the northwest corner of the next township to the south.

Occurrence

The Burnstad drift is bounded on the north and west by the Long Lake drift and on the northeast by the Streeter drift.

Lithology

Both the end moraine and the dead-ice moraine consist of stony clay till. Boulders are plentiful, particularly in the area of the dead-ice moraine.

Thickness

Near the distal margin of the end moraine, test hole No. 1047 (Fig. 7) penetrated 332 feet of till under 60 feet of sand and gravel. The dead-ice moraine is probably less than 25 feet thick 3 miles north of Alkaline Lake, where the Fox Hills Formation is exposed in roadcuts.

Topographic Expression

Twin Buttes End Moraine

The Twin Buttes end moraine represents the northernmost loop of the Burnstad drift and it is apparently overlain by the Lake George loop of the Streeter end moraine in the vicinity of Lake George. Much of the Burnstad drift north and east of Alkaline Lake has been buried by Streeter outwash derived from the east in Stutsman County. This outwash has been channeled down a partly buried preglacial valley which trends toward Lake Isabel from the southeast corner of the county.

The border of the loop is marked by a relatively high and irregularly shaped ridge of end moraine. A belt of dead-ice moraine lies behind the end moraine and is second only to the dead-ice moraine in northern Kidder County in areal extent. The contact between the end and dead-ice moraine is difficult to locate, but generally has been placed at the base of the proximal slope of the end moraine. The surface of the highest ridges in the dead-ice moraine immediately adjacent to the end moraine are 50 to 75 feet lower than those in the end moraine.

The topography of the end moraine consists of hillocks and irregularly shaped shallow depressions which display crude arcuate trends on air photographs. The dead-ice moraine, devoid of curvilinear trends, consists of a maze of steep-sided kettles separated by bouldery ridges.

A minor readvance of the ice lobe which deposited the Twin Buttes loop occurred to produce the Fresh Lake loop in the southeastern corner of the county.

Relation to Other Drifts

The Burnstad drift truncates the southeast flank of the Long Lake end moraine and is apparently overlapped by the Lake George loop of the Streeter drift to the northeast.

Tentative Correlation

The Burnstad drift is tentatively correlated by Lemke and Colton (1958, p. 49-50) with the A-1 (Mankato) advance of Flint (1955, p. 119). Since the Twin Buttes end moraine is herein referred to the Burnstad drift, this tentative correlation is accepted.

Spruce wood from sand overlying the till of the Twin Buttes end moraine was radio carbon dated at 11,480 ± 300 years (Moir, 1958, p. 109-110.)

STREETER DRIFT

General Statement

The Streeter drift (Plate 1) consists chiefly of end moraine, dead-ice moraine, and outwash. Kames, eskers, outwash channels, and kettle chains are associated with the Streeter drift.

Outcrops of the Tongue River, Cannonball, and Fox Hills Formations were mapped in the areas of the bedrock highs.

Occurrence

The Streeter drift is bordered on the south by the Burnstad drift and on the west by the Long Lake drift. Outwash beyond the limits of the Streeter end moraines and dead-ice moraines is undifferentiated, but most of it was derived from drift of the Streeter advance.

The Streeter end moraines have considerably more relief than those of the Long Lake advance.

The northern two tiers of townships are almost entirely covered by Streeter drift, and on the east side of Kidder County, the Streeter end moraine loops are prominent from south of the town of Pettibone to the vicinity of Lake George.

Lithology

The end moraines and dead-ice moraines are composed of stony clay till. The outwash, kames, and eskers, are composed chiefly of sands and gravels with lenses of till. More detailed discussions of lithology are included with the descriptions of the individual land forms below.

Thickness

The thickness of the deposits which are referred to the Streeter drift varies widely. In the Lake Williams Loop, the maximum observed thickness of the till is 12 feet. In the Woodhouse Lake Loop, the till reaches a maximum observed thickness of 18 feet. The thickest exposure of till observed in the dead-ice moraine is 30 feet thick.

The outwash generally varies in thickness from 3 to 40 feet, with much greater thicknesses in buried outwash channels (Figs. 7, 8, and 12).

TOPOGRAPHIC EXPRESSION

End Moraine

Woodhouse Lake Loop

The Woodhouse Lake Loop (Plate 1) is named for the lake in the northeast corner of T. 144 N., R. 74 W. To the north, in Wells County, there is a bedrock high near the middle of the moraine. That portion of the moraine east of the bedrock high is the highest moraine in Kidder County. In Wells County, the relief of the moraine is much less and the end moraine becomes unrecognizable as it merges into dead-ice moraine. Only a small portion of the western part of the moraine is present in Kidder County, west of the bedrock high.

An outcrop of Fox Hills Sandstone occurs within the margins of the Woodhouse Lake Loop in Section 24, T. 144 N., R. 71 W. The bedrock there dips to the southwest at about 70 degrees and has a strike essentially parallel to the end moraine. Indeed, the crest of the ridge in this area might be underlain by tilted beds of Fox Hills Sandstone, in which case the buried bedrock high might extend for a distance of 6 miles along the center of the moraine where the crest is at about the same elevation. The presence of bedrock in the moraine is suggested by linear trends evident on air photographs and the integrated drainage pattern reflected through the thin veneer of drift.

The tills on both sides of the bedrock high are calcareous, having colors which range from light olive gray (5 Y 6/1) to pale yellowish brown (10 YR 6/2) when dry. The wet till from both segments is dark yellowish brown (10 YR 4/2). Irregular concentrations of hematite and limonite locally color it a mottled yellow and gray. Several exposures show an accumulation of calcium carbonate. Pebble counts in both the eastern and western segments show a similar percentage of limestone and dolostone pebbles.

The maximum thickness of till exposed in roadcuts through the Woodhouse Lake Loop is 18 feet.

The outwash of the Woodhouse Lake Loop occurs in discontinuous patches south of the margin of the moraine. Flint (1955, p. 65) found that discontinuous outwash bodies are common along the end moraines of Mankato age in eastern South Dakota. He accounts for the discontinuity of the outwash by stating that the drainage could possibly have originated not at the margin of the glacier, but farther back upon or within the ice. The drainage would then issue at the margin of the ice only at hydrologically favorable points after the stream flow had integrated. Similar discontinuous outwash deposits occur on the distal side of the Woodhouse Lake Loop.

Lake Williams Loop

The Lake Williams Loop (Plate 1) lies north of Lake Williams, North Dakota, the village for which it is named. The end moraine borders a large area of dead-ice moraine and is flanked by outwash.

The end moraine consists of groups of subparallel ridges, which are conspicuous on air photographs. The number of ridges ranges fram 8 to 10 per mile. Groups of ridges are well developed in Sections 19, 20, and 33, T. 143 N., R. 70 W.

The till of the Lake Williams Loop has certain distinguishing characteristics, most important of which is the predominance of sand and gravel. The Woodhouse Lake Loop, on the other hand, has little sand and gravel associated with its till. Good exposures of gravelly till in the Lake Williams Loop occur in roadcuts on the section line road between Sections 19 and 20, T. 143 N., R. 70 W. The light olive gray (5 Y 6/1) colored till of this loop is generally similar to that of the Woodhouse Lake Loop to the north. Locally, however, the Lake Williams till was found to be yellowish gray (5 Y 7/2) and light gray (N 7) where freshly exposed, and olive gray (5 Y 4/1) when wet.

Pebble counts made in the Lake Williams Loop show that its till contains an average of 67 per cent of limestone and dolostone pebbles. On the other hand, the till of the Woodhouse Lake Loop contains an average of 59 per cent of limestone and dolostone pebbles. The difference in the percentage of carbonate rock pebbles in the two tills might indicate that they have been derived from two different source areas, through the writers are inclined to doubt this.

Small patches of stratified drift on the distal slopes of the end moraines were deposited by meltwater streams from the flanks of the ice terminus.

McPhail Buttes Loop

The McPhail Buttes Loop is named for the McPhail's Butte Historic Site in Section 4, T. 140 N., R. 71 W. The McPhail Buttes Looop becomes less distinct about 4 miles southwest of Pettibone, where it merges into stagnation moraine deposited shortly after the maximum advance of the ice. Further, it is fringed by outwash deposits of sand and gravel which were derived from the Streeter advance. Streeter outwash has partly buried the northern limb of the McPhail Buttes Loop southwest of Pettibone.

The difference in elevation between the crest of the end moraine and the outwash to the south and southwest ranges from 150 to 200 feet. Knob and kettle topography is not so apparent as that found to the southwest in the Long Lake Loop, but there are prominent linear trends in the moraine.

On the western nose of the moraine in T. 140 N., R. 71 W., an elongate finger of till, which is esker-like in appearance but lacking in sand and gravel, projects to the west above the adjacent ground moraine. This might represent part of an older buried loop between the Long Lake and Streeter advances, but evidence is lacking to document this theory.

Crystal Springs Loop

A broad arc of end moraine occurs between the United States Interstate 94 and the McPhail Buttes Loop, and is herein called the Crystal Springs Loop for Crystal Springs, North Dakota (Plate 1). The Crystal Springs Loop appears to be truncated by the McPhail Buttes Loop. The central part of this loop has the greatest relief and the topography consists of numerous knobs and undrained depressions.

The end moraine is partly overlapped by outwash in the interlobate area west of Crystal Springs.

Dead-ice moraine occurs on both sides of the Crystal Springs Loop. Many undrained depressions are irregularly dispersed over a rolling surface with less than 30 feet of relief and devoid of linear trends.

Lake George Loop

The Lake George Loop (Plate 1) southeast of Crystal Springs, North Dakota, is 10 miles long between Lake George on the south and United States Interstate 94 on the north. It is continuous with the Crystal Springs Loop, except for the outwash deposits which parallel the highway in the interlobate area.

The topography behind the end moraine is dominated by the knobs and undrained depressions of dead-ice moraine. The Lake George Loop is separated from the Twin Buttes moraine to the southwest by an outwash filled valley which trends northwest toward Lake Isabel.

Dead-ice Moraine

Approximately one-fourth of the county is covered by dead-ice moraine and bedrock highs which are covered by a thin veneer of till derived from stagnant ice. The dead-ice moraine commonly has a relief ranging from about 20 feet to more than 100 feet, and averaging about 50 feet. Dead-ice moraine having less than 20 feet of local relief, however, could not be distinguished easily from ground moraine.

The greatest thickness of till exposed in the dead-ice moraine is 30 feet and is located in Section 18, T. 144 N., R. 73 W. The logs of test holes of the United States Geological Survey reveal that the till in areas of dead-ice moraine ranges in thickness from 3 feet in test well No. 1153, in Section 22, T. 144 N., R. 74 W., to 100 feet in test well No. 1150, in Section 30, T. 143 N., R. 72 W. Sand and gravel in lower 67 feet of test well No. 1150 might represent an older drift.

The till of the dead-ice moraine in northern Kidder County is generally calcareous, bouldery, clay-rch, and is light olive gray (5 Y 6/1) to pale yellowish brown (10 YR 6/2). The till of dead-ice moraine generally lacks fissility and is less compact than the till of either end or ground moraine.

The most characteristic form of the dead-ice moraine is its knob and kettle topography. At places, sinuous ridges are interspersed with kettles. The kettles range considerably in size, but average between 0.1 and 0.2 mile in diameter. The typical topography associated with dead-ice moraine is well developed in T. 144 N., R. 73 W., Kidder County.

Ground Moraine

Only one small area of ground moraine, in T. 144 N., R. 70 W., is associated with the drift of the Streeter advance. In this area of swell and swale topography and low relief, the ground moraine is composed of calcareous stony clay till.

STRATIFIED DRIFT

Kettle Chains

Kettles and other undrained depressions are commonly partly filled with stratified drift in the dead-ice moraine of northern Kidder County. Some kettles occur in chains and indicate preglacial or interglacial valleys in which the ice persisted. An example of a kettle chain is shown in T. 142 N., R. 73 W. The kettle chain becomes less distinct about 4 miles east of its point of origin. The maximum local relief of the kettle chain is 60 feet and it is surrounded by outwash, except on its western end, where it is bordered by till. Ice blocks originally occupied the kettle chain, but with melting, the adjacent stratified drift slumped into the channel.

Kames

Most of the kames of the Streeter drift occur in dead-ice moraine. The kames average 0.2 mile in diameter and 40 to 50 feet in height. Kames occurring in dead-ice moraine generally are cone-shaped hills composed of sand and gravel. The stratification of the constituent materials was locally disturbed by faulting when the supporting ice melted and the stratified material collapsed. A sieve analysis of stratified drift from a typical kame indicates that about 30 per cent of the material is over 4 mm. in diameter.

A large kame in Section 7, T. 140 N., R. 70 W., consists of poorly to well bedded sand and gravel which is locally slumped. A large gravel pit in this kame was being operated in 1959.

Another relatively large kame in Section 25, T. 140 N., R. 70 W., provided sand and gravel for the construction of United States Interstate Highway 94. The deposit was predominantly cross-bedded sand and gravel with lenses of silt, locally slumped and faulted.

A kame in Section 23, T. 139 N., R. 70 W., shows stratified sand and gravel with minor slumping on its eastern flank.

Eskers

An esker-like feature associated with drift of the McPhail Buttes Loop occurs in Section 3, T. 140 N., R. 70 W. Samples of sand and gravel were obtained from auger holes. Another esker trends west in Section 12, T. 140 N., R. 70 W., and extends into Section 7, T. 140 N,. R. 69 W., of Stutsman County. Augering produced sand and pebbles from beneath a thin veneer of till.

An esker over 1,000 feet long, showing cross-bedded sand and gravel, occurs in Section 12, T. 140 N., R. 71 W.

An esker in Section 5, T. 144 N., R. 73 W., averages 50 feet in width and is over 20 feet in height. A sieve analysis indicates that 47 per cent of the material ranged between ¼ and 1 mm. This esker merges into the Woodhouse Lake Loop which lies immediately to the north. Boulders on its surface become more abundant adjacent to the end moraine.

Another esker lies along the distal edge of the Lake Williams Loop in Section 29, T. 143 N., R. 71 W. This esker is composed of stratified sand and gravel with boulders up to 2 feet in diameter on its crest.

An esker in Section 22, T. 143 N., R. 74 W., is about 10 feet in height with an average width of 50 feet. Its form is subdued by later dead-ice moraine.

Outwash

A broad expanse of outwash covers approximately one-third of the county with coalescing outwash plains between Tuttle and Pettibone and south to Long Lake. The outwash is variable in texture, depending upon the proximity of its source area, and becomes especially coarse close to the border of the Streeter drift, from which is was derived. Meltwater flowing from the stagnant ice discharged to the south from various places along the ice border between Tuttle and Pettibone, forming a massive outwash plain as the alluvial fans of each stream coalesced.

The meandering meltwater streams spread successive layers of sand and gravel over the area. As the outwash spread southward, the coarser and heavier material was deposited first. Abundant evidence for this occurs in roadcuts along North Dakota 36 from Tuttle west to the Burleigh County line. Some cuts along the Northern Pacific Railroad in this vicinity expose more than 20 feet of sand and gravel. About 5 miles south of the margin of the dead-ice moraine, the outwash consists of medium to fine-grained sand and the outwash plain has a gradient of about 3 feet per mile.

Some of the streams which flowed from the ice front carried outwash to the proximal side of the Long Lake moraine nearly 8 miles to the south. Hence, the deposits in the area close to the Sibley Buttes are dominated by the fine size fractions of sand and silt washed out of the moraine to the north by meltwater. Evidence that the outwash plain south of Tuttle was built largely of material derived from the north is threefold: (1) the outwash plain gradually slopes southward, (2) the grain size decreases to the south, and (3) the stratification planes within the outwash commonly dip 1 to 4 degrees to the south in Section 26, T. 142 N., R. 74 W. Outwash of the Streeter advance has partly buried some deposits of the Long Lake till south of Tuttle, but a few hills of the till occur in parts of Sections 26, 27, 34, and 35, T. 142 N., R. 74 W., and in parts of Sections 16, 17, and 18 in the same township.

Outwash Near Pettibone

The outwash plain in the Pettibone area covers about 70 square miles between the Lake Williams and McPhail Buttes Loops (Plate 1). The outwash deposits generally become coarser towards the end moraine and a single outwash exposure might have material which ranges in size from silt to boulders. Sieve analyses show that the outwash deposits average 30 per cent gravel, 68 per cent sand, and 2 per cent silt and clay.

Locally, the upper few feet of the outwash is colored yellowish brown with limonite derived from the decomposition of ferromagnesian minerals. The high permeability of the outwash allows surface water to be absorbed rapidly forming important groundwater reservoirs.

The depth of weathering of the outwash is generally 1 to 2 feet. In the weathered zone, feldspar is partly decomposed and partial oxidation of ferromagnesian minerals has occurred The result of the weathering is to add more clay-sized material to the outwash.

On the distal side of the Lake Williams moraine in Sections 33, 34, and 35, T. 143 N., R. 70 W., the surface of the outwash deposit slopes gently toward the end moraine. The original slope of the surface in this area was away from the end moraine, but because part of the outwash was spread over ice blocks which eventually melted, the slope was reversed. The amount of collapse was greatest next to the Lake Williams Loop, where the buried ice was thickest.

Outwash Near Dawson and Tappen

Approximately one-half of central Kidder County is covered with outwash in T. 139 N. and 140 N., and R. 71 W. and 72 W., respectively. A western extension of this material occurs in the northeast and southeast part of T. 139 N., R. 73 W., and along the eastern margin of T. 140 N., R. 73 W. The outwash is overlain in part by patches of younger alluvium, which generally occur in the lake and slough bottoms. The deposit was formed by coalescing meltwater streams from the end moraines of the Streeter advance to the east. This is indicated by the gradual coarsening of the outwash toward the end moraine.

Knobs of till protrude above the outwash plain in Section 25, T. 141 N., R. 72 W. A more extensive area of till not covered by outwash occurs southwest of Sibley Lake.

The thickness of the outwash ranges from 3 to 40 feet. Logs of test holes were used to determine the thickness of the stratified drift and 16 of the logs indicate an average thickness of the sand and gravel deposit of 23 feet (Figs. 7, 8, 14, and 15).

The central part of the major outwash area in central Kidder County contains thicker outwash, for it was the center of the drainage basin. Several cross-sections (Figs. 7, 8, and 12) indicate that the thicker outwash deposits coincide with the course of the preglacial Cannonball River (Fig. 16). Long Lake is located along the course of this ancient stream which flowed northeast between the present villages of Dawson and Tappen, North Dakota, north toward Stony Lake and east into Stutsman County.

This large outwash area is nearly flat and the relief is commonly less than that of ground moraine. In some localities, boulders occur on its surface which might have been rafted to their present positions on icebergs.

Lake Deposits

Lake deposits are distinguished from other sediments because of their characteristic laminated bedding. A small exposure of alternating silt and clay laminae occurs 0.7 mile west of the northeast corner of Section 19, T. 144 N., R. 73 W., in stagnation moraine. Light brown laminae alternate with dark brown laminae, producing rhythmites.

Other temporary lakes existed in the stagnant ice, but exposures of laminated sediments are rare in the county.

Loess

Because of its limited areal extent, loess was not designated on the geologic map. However, certain significant deposits should be mentioned with respect to the Streeter advance. An exposure of loess occurs 0.8 mile north of the southeast corner of Section 31, T. 143 N., R. 71 W. The loess here overlies outwash and is 2 feet in thickness. Its color is yellowish gray (5 Y 7/2) and it is composed mainly of subangular to subround silt size particles of quartz, calcite, feldspar, and chert, with minor amounts of other minerals. This deposit was oxidized throughout its entire thickness. Loess commonly takes on a yellowish hue due to ferric oxides because it is permeable and is subject to rapid and deep oxidation (Flint, 1955, p. 68). Loess associated with glacial deposits is commonly blown from the surface of outwash plains and deposited wherever the wind velocity decreases rapidly.

Relation to Other Drifts and Tentative Correlation

The Streeter drift overlies the Long Lake drift. The Burnstad drift in southeastern Kidder County is apparently overlain by the Streeter drift, but the two moraines are believed to be very nearly time equivalent with the Streeter drift representing a re-advance of the same ice sheet that deposited the Burnstad drift.

Lemke and Colton (1958, Fig. 3) correlate the Streeter Drift with the B-1 (Mankato) advance of Flint (1955, Plate 1, p. 119).

DRAINAGE HISTORY OF KIDDER COUNTY

Existing Drainage

The topography is youthful and consists mainly of undrained depressions; hence, no major integrated streams have developed. Many small intermittent streams drain into the larger lakes. In central Kidder County, most of the drainage is into Horsehead Lake. Moreover, a few intermittent streams heading near the Burleigh County line in the northwestern corner of the county pass through north-central Kidder County into Cherry Lake 6 miles southeast of Tuttle, North Dakota. Chase Lake in west-central Stutsman County receives some surface water from northeastern Kidder County. In the south, the streams drain into the Long Lake trough, which also contains Lakes Etta and Isabel 3 miles south of Dawson, North Dakota. Lake George and Alkali Lake receive the discharge from surface streams in the southeastern corner of the county. By far the majority of the intermittent streams which head in the large end, dead-ice, and recessional moraines flow into small lakes and sloughs or disappear by infiltration into outwash.

Evidence of Former Drainage

In preglacial time, the drainage system in North Dakota flowed into Hudson Bay (Todd, 1914; Flint, 1955, p. 140; Lemke and Colton, 1958, Fig. 2). Further, the ancestral Cannonball River flowed northeast through south-central Kidder County (Fig. 16). Indeed, the preglacial Cannonball might have been a tributary to the ancestral Red River (Lemke and Colton, 1958). The ancient Cannonball River initially flowed northeast across the county from the vicinity of Long Lake where the old valley is still clearly discernible, though it has been partly filled with glacial drift. The logs of test wells have helped to trace its course through the site of present Lake Isabel to Chase Lake in west-central Stutsman County (Figs. 7, 8, 12, 14, and 15). Todd (1914, p. 266) suggested that the Long Lake trench represents the former course of the Cannonball River. However, its course east of Long Lake has been speculative because the trench has been completely buried by thick glacial drift, making it difficult to follow. Fortunately, the writers had access to data provided by logs of test holes of the United States Geological Survey and have been able to trace the course of this important buried valley.

The Long Lake trough is connected with the present valley of the Cannonball River of Grant, Sioux, and Morton counties by means of the following evidence. Today the Cannonball enters the Missouri River about 25 miles southwest of the western edge of Long Lake. The trend of Long Lake is nearly aligned with the present course of the Cannonball between Grant and Sioux counties. Four miles north of the present mouth of the Cannonball River on the east bank of the Missouri River, is a large abandoned valley that leads northeast from the Missouri trench through northwest Emmons County across southeast Burleigh County and connects with the valley which encloses Long Lake in Kidder County. The dimensions of the valley indicate that it once contained a large river. The 4-mile segment of the Missouri River trench between the mouth of the Cannonball and the large open valley north of it is a part of the pre-diversion Cannonball River. Clearly, the Cannonball River valley unites with the Long Lake trench.

Even though the valley of the Cannonball is buried in Kidder County, test hole drilling has revealed something of the character of the old valley profile (Figs. 7 and 8). The valley of the preglacial Cannonball River was more than a mile wide and ranged between 100 and 300 feet in depth. Its main valley was paralleled by a series of terraces which extend for 1 to 2 miles on each side of the river. The bedrock walls of the valley are cut in Fox Hills Sandstone in southwestern Kidder County and in Emmons County. Farther east, the valley is cut in the Pierre Shale.

Two major tributaries fed the ancestral Cannonball River in Kidder County (Fig. 16). One of the large streams rose in the northeast corner of Logan County and flowed northwest between Alkali Lake and Lake George for 10 or more miles to join the Cannonball near Lake Etta. Its old valley is partly exposed about 1 mile southwest of Lake George. This river is herein named the Logan River, for its headwaters were derived from tributaries in northeastern Logan County. Another stream flowed eastward from the northwest corner of Kidder County near Tuttle, North Dakota, and joined the ancient Cannonball River southeast of Horsehead Lake. Its headwaters came from northeastern Burleigh County near Wing, North Dakota, and this river is herein named the Wing River. Its valley extends more than 11 miles between Wing and Horsehead Lake. Both of these tributaries have wide valley floors and valley walls cut into the Fox Hills Sandstone in the Logan River valley and the Tongue River Formation in the Wing River valley. Low bluffs with gentle slopes rise adjacent to the main valley of the Logan River near Alkali Lake and Lake George, and the Fox Hills Sandstone crops out in roadcuts in each area.

Another major preglacial stream to the north of the ancient Cannonball River was the Knife River, which flowed to the northeast and essentially parallel to the Cannonball (Lemke and Colton, 1958, Fig. 2). The drainage of northern Kidder County was to the south and east into the Wing and Cannonball rivers because the majority of the dendritic drainage patterns developed in the bedrock highs of northern Kidder County indicate that the major streams drained to the south. The major preglacial drainage channels in the north have been reconstructed from the position and extent of known bedrock highs and elevations on the bedrock surface in the test wells (Fig. 16).

The depth to bedrock in the main valley of the ancestral Cannonball River 5 miles south of Steele between Long Lake and Lake Etta is 300 feet (Fig. 8). The difference in elevation between the depth to bedrock at Steele, on the old upland surface, and the bedrock floor of the Cannonball south of Steele is over 475 feet. Thus, the preglacial surface had considerable relief along the old river valley and the landscape must have resembled the high bluffs which flank the Missouri River trench in North and South Dakota.

The Cannonball turned northeast from Lake Etta, heading between Dawson, North Dakota, and Lake Isabel. The depth to bedrock on the floor of the ancestral Cannonball valley 1 mile north of Lake Isabel is 332 feet and the elevation on the bedrock surface is 1420 feet (Fig. 7). Hence, the gradient of the valley floor is 22 feet in 10 miles. The Cannonball turned sharply northeast from Lake Isabel and passed 6 miles north-northwest of Tappen, where the elevation on the bedrock floor is 1395 feet or about 25 feet lower than it was 9 miles upstream (Fig. 12). From Sibley Lake, the old river trended nearly due east toward Chase Lake in west-central Stutsman County, where data are lacking regarding its course. Another tributary flowed into the ancestral Cannonball River from the northeastern corner of the county, about 2 miles east of Lake Williams, North Dakota, where the elevation of the bedrock is about 1450 feet (Fig. 9).

The Logan River flowed into the Cannonball north of Lake Henry. The elevation on the bedrock surface in the main valley of the Logan River, about 7 miles south of Tappen on the east side of Lake Henry, is 1442 feet (Fig. 14, test well No. 1049). Thus, the elevation of the Logan River valley was 365 feet below the present surface of Lake Henry. The bedrock surface only 2½ miles southeast of this location is 365 feet higher at an elevation of 1707 feet (Fig. 14, test well No. 1042). The amount of relief along its valley between Lake George and Alkali Lake must have been at least as great as that along the Cannonball in the south-central part of the county in the Long Lake trench. There can be little doubt that these major rivers were deeply entrenched in the plateaulike highlands of the Coteau du Missouri and that their tributaries also were deeply dissected and flowing in relatively steepwalled valleys.

The Wing River presumably flowed at a steeper gradient and in a smaller valley than either the Cannonball or the Logan River. About a mile west of Tuttle, the elevation on the valley floor is 1665 feet, whereas 1 mile north of Cherry Lake, the elevation on the bedrock is less than 1640 feet, and at the west side of Horsehead Lake, the valley floor dropped to an elevation lower than 1590 feet (Figs. 9, 10, and 12).

The benefits that accrue from a careful study of the courses of these buried valleys and their deposits are twofold. The deposits within the buried valley might yield considerable quantities of ground-water, providing sufficient thicknesses of permeable material are found. Moreover, the knowledge gained from a study of the ancient rivers of North Dakota helps to unravel the complex history of the Pleistocene Age, and hence, promotes a better understanding of preglacial landscapes and their subsequent modification by glaciers.

Rearrangement of Drainage

The ancestral Cannonball River and its tributaries were blocked by ice moving west across the Coteau du Missouri and the lakes thus formed received sediments from meltwater streams. Eventually, the lakes overflowed and spilled water southward and westward over the preglacial bedrock divides. The Cannonball River probably overflowed to the south in Burleigh County, as did the Wing River, while the Logan River was backed up until it overflowed in Logan County. The location of these spillways is not known and must await the geologic mapping of Burleigh and Logan counties.

SYNTHESIS OF THE GLACIAL HISTORY

Kidder County was covered with glacial ice at least three times during the Wisconsin Stage of the Pleistocene, but no definite evidence of pre-Wisconsin glaciation has been found in the State. Clearly, several drifts were deposited in parts of North Dakota, but the entire sequence of drifts has not been observed in one exposure.

Older drift was overridden by a sheet of ice of the Long Lake advance, which entered the county from the east and northeast. The initial lobes of the Long Lake advance followed the bedrock lows of preglacial valleys. A lobe of glacial ice pushed along the valley of the ancestral Cannonball River south of Steele and deposited a great loop of moraine in the southwestern corner of the county in the vicinity of Long Lake. Ground moraine was deposited as these lobes melted back to the east.

Glacial Lake Steele formed in a shallow nearly elliptical depression in the vicinity of Steele. The outwash area located in the southwest corner of T. 139 N., R. 73 W., also originated at about the same time as the lobes melted back to the east, freeing the ancestral valley of the Cannonball River of ice.

At its maximum, the ice sheet covered the bedrock highs of the northern and southern parts of the county. The ice sheet must have been thin over the uplands, for the drift there is so thin that bedrock is exposed in a number of places and the integrated drainage developed on older drift and the plateau surface is still discernible through the surficial drift. The ice melted and deposited dead-ice moraine over the bedrock highs adjacent to the main valleys behind the end and interlobate moraines of the Long Lake advance. With the melting of the ice sheet, the valleys were filled with outwash and ponded sediments because the meltwater was confined behind the end moraines which dammed both the ancestral Cannonball and Wing Rivers.

The next ice lobe deposited the Twin Buttes end moraine and associated dead-ice moraine of the Burnstad drift in southeastern Kidder County over the drift of the Long Lake advance.

The next episode of glaciation is marked by the drift of the Streeter advance and was confined mostly to the eastern margin of the county. A series of loops of end moraine extends from Pettibone on the north to Lake George on the south.

In the north, the position of the drift border of the dead-ice moraine indicates that the ice which deposited this moraine moved into the county from the northeast. Following the advance of this ice, dead-ice moraine was deposited on older till and locally on bedrock beneath the ice. Upon melting, this drift was deposited over the northern tier of townships in the county. Logs of test holes show that at least part of the dead-ice moraine in the northeastern corner of the county is separated from an older till by outwash (Fig. 10) and presumably the older till was deposited during the Long Lake advance.

Minor readvances of an ice lobe located in Stutsman County to the east occurred during the shrinkage that followed the maximum expansion of the Mankato ice of Flint (1955, p. 118). The Lake Williams Loop in the northeastern corner of the county might have been formed during one of these minor readvances, but it is herein considered part of the Streeter advance. The Woodhouse Lake Loop was deposited along the northern boundary of the county as the Streeter advance melted back to the northeast.

The Streeter advance supplied meltwater which covered the older drift with a vast sheet of outwash extending from Robinson on the north to Lake George on the south and filling both of the major bedrock valleys with stratified drift. The amount of meltwater was sufficient to breach both the end moraines of the north and south loops of the Long Lake moraine. Moreover, these old stream valleys served as passageways for the sediment-laden water discharged from the terminus of the Streeter ice advance. Outwash from this advance was carried along these trenches to the west beyond the borders of Kidder County.

The Streeter ice sheet must have been thin, for dead-ice moraine was deposited behind each of the major loops of end moraine along the eastern boundary of the county.

In conclusion, it is clear that each ice advance has been slowed and finally halted by the buttes and mesas which comprise the eastern border of the Coteau du Missouri in North Dakota. Each major advance was followed by a prolonged period of melting and stagnation, resulting in the deposition of a widespread deposit of dead-ice moraine behind each end moraine and large sheets of outwash in front of their termini.

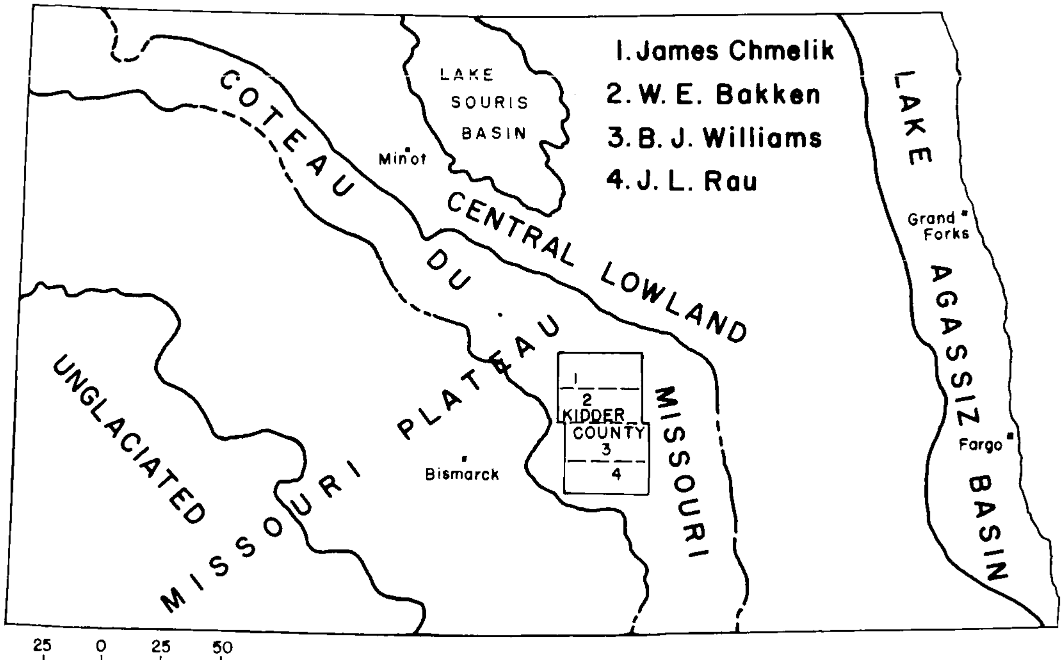


Figure 1. Location Map, Kidder County.

Location Map of Kidder County showing portions mapped by each of the authors.

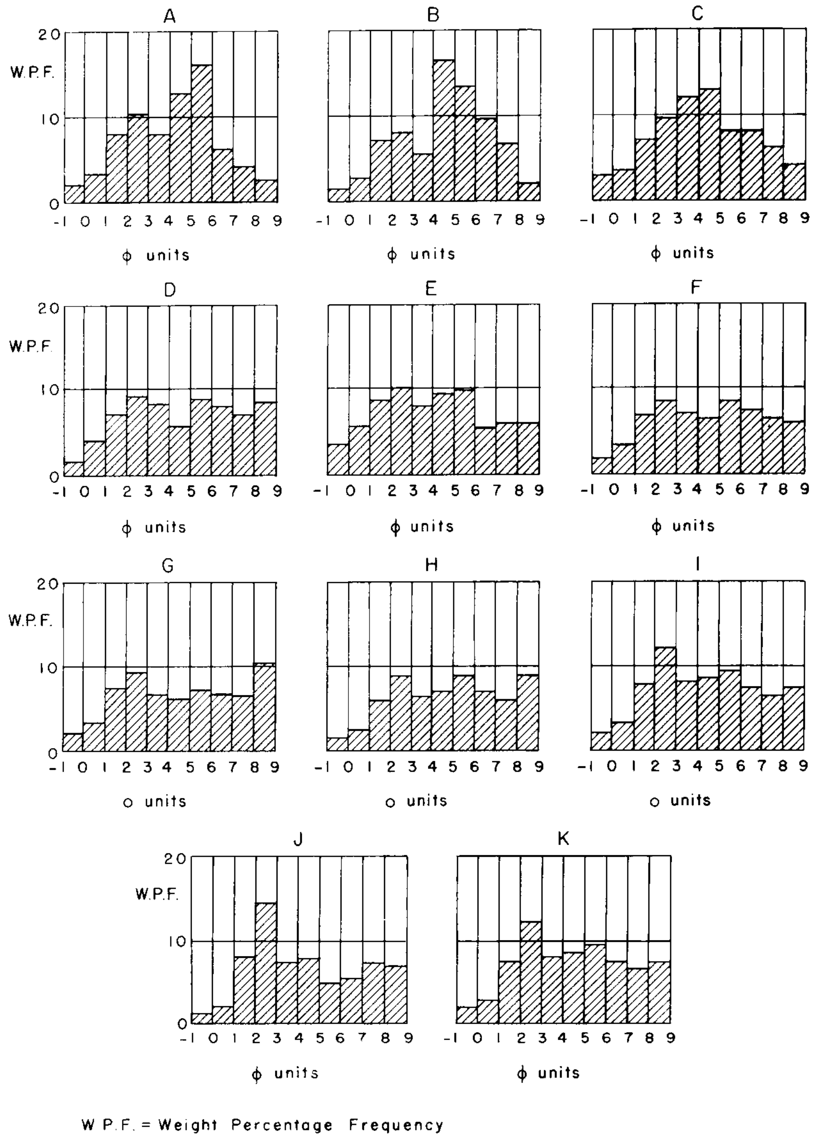


Figure 2. Histograms showing grain-size frequencies in eleven samples of Kidder County tills. A. C1-10-A; B. C1-10-B, C1-10-C; D. C1-20; E. C1-37-B; F. C1-37-E, G. C1-57; H C1-87; I. C1-89. J. C1-97; K. C1-107. See text page 10, and Table 1 (after Clayton 1960).

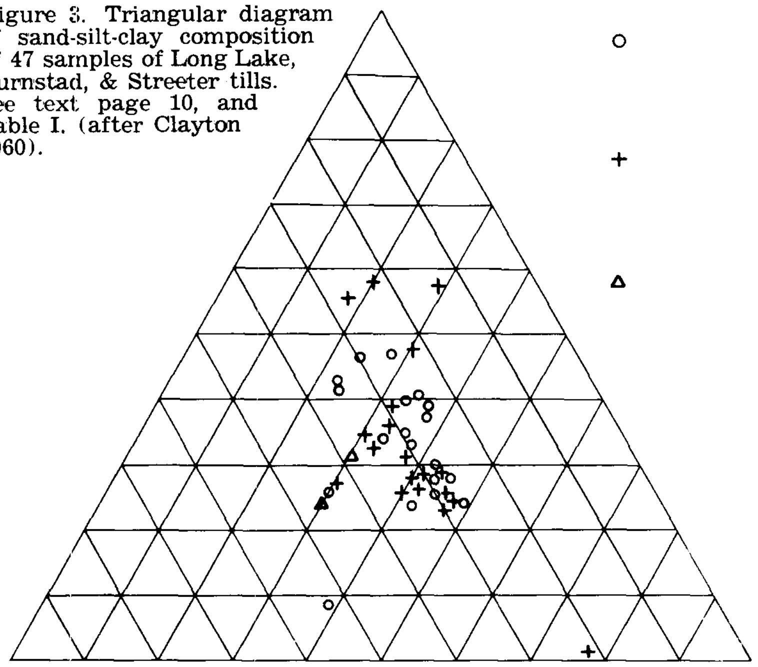


Figure 3. Triangular diagram of sand-silt-clay composition of 47 samples of Long Lake, Burnstad, & Streeter tills. See text page 10, and Table I. (after Clayton 1960).

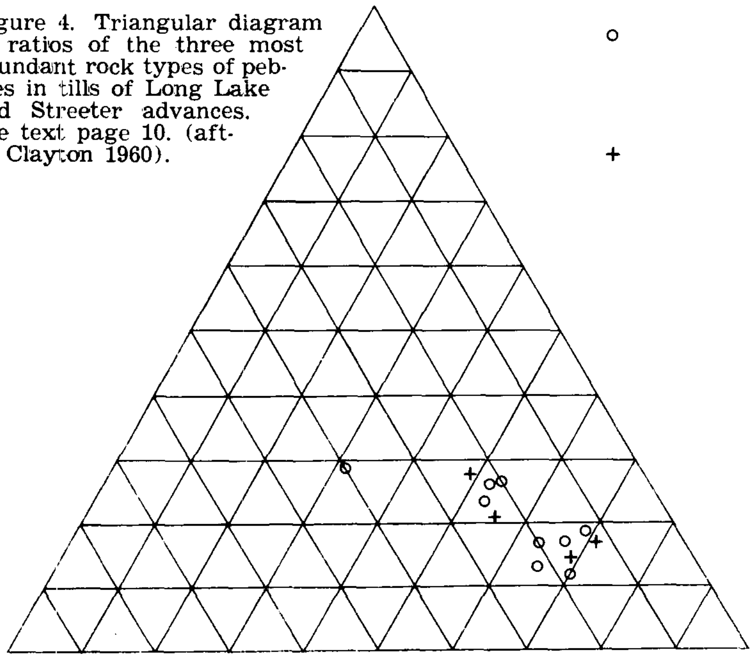


Figure 4. Triangular diagram of ratios of the three most abundant rock types of pebbles in tills of Long Lake and Streeter advances. See text page 10. (after Clayton 1960).

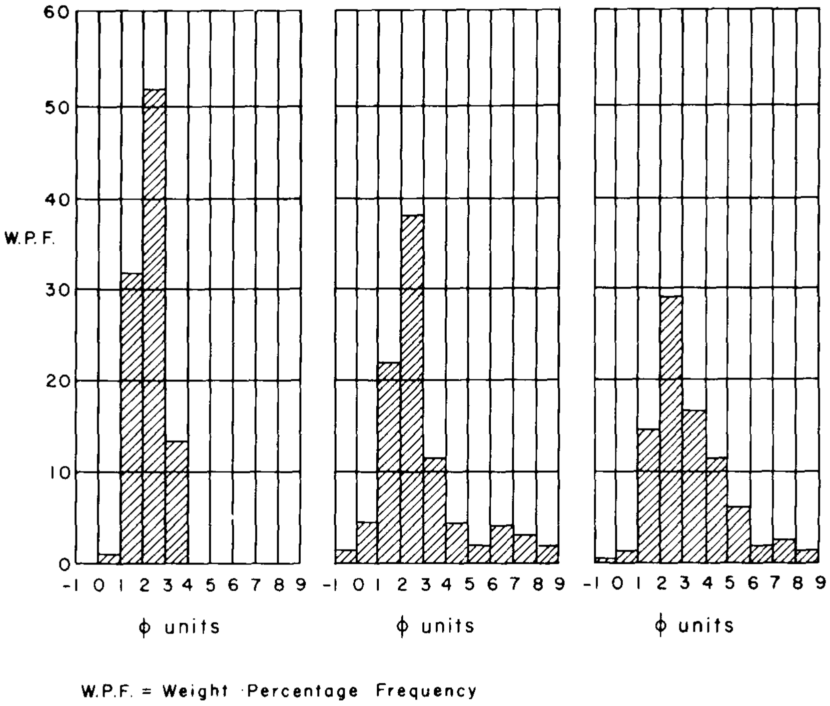


Figure 5. Histograms showing grain-size frequencies in two samples of loesslike sand and one sample of dune sand. A. C1-8; due sand from NW¼ sec. 15, T. 138 N., R. 72 W.; B. C1-35; loesslike sand from 0.2 mi. S. of NE corner sec. 29, T. 138 N., of SE corner sec. 6, T. 137 N., R. 71 W. See text page 17. (After Clayton, 1960).

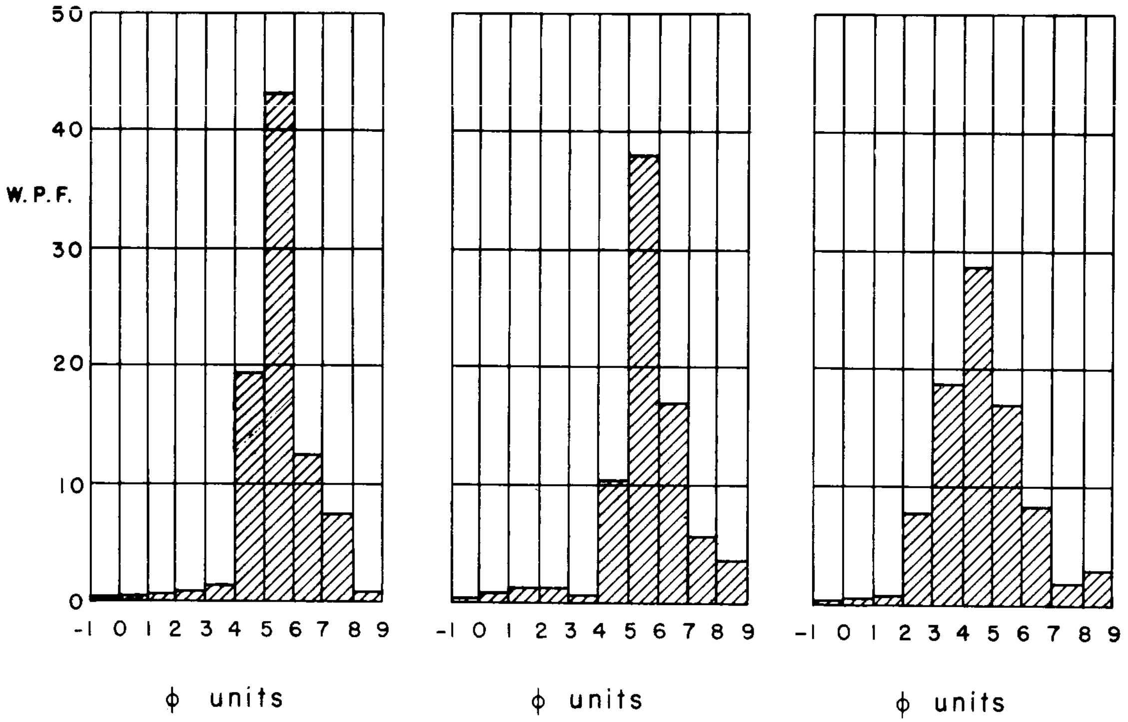


Figure 6. Histograms showing grain-size frequencies in three samples of loess. A. C1-37-D; B. C1-7; C. C1-52. See text page 10, and Table I. (After Clayton, 1960).

W.P.F. = Weight Percentage Frequency

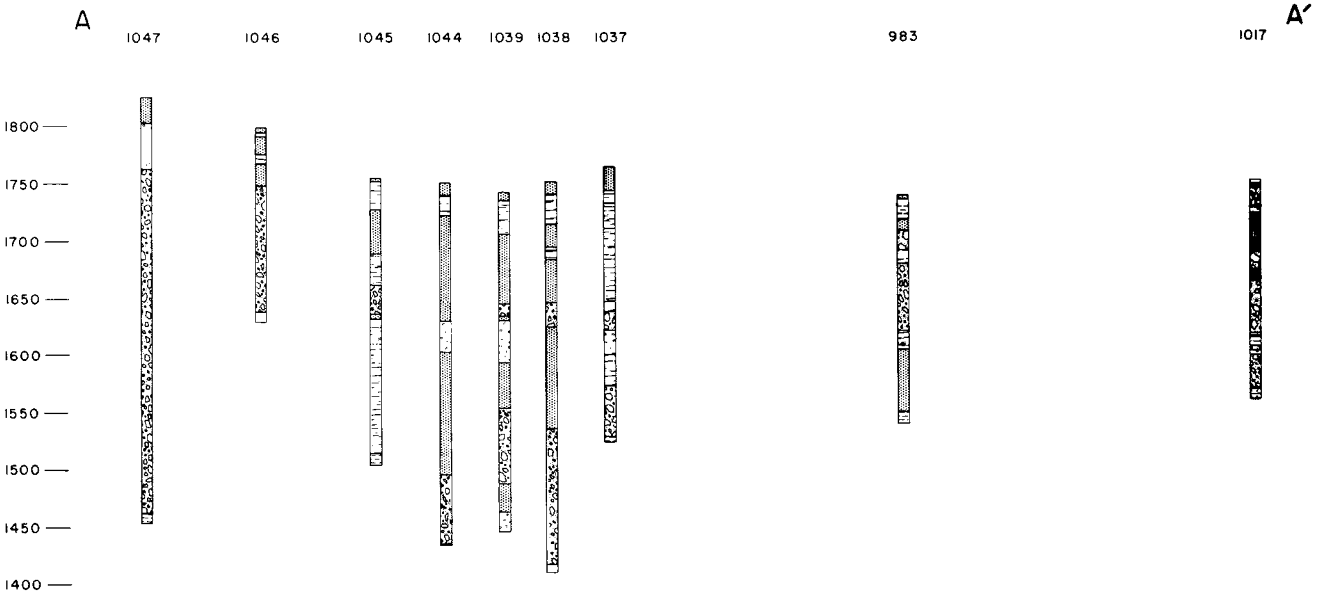


Figure 7. Cross-section A-A'.

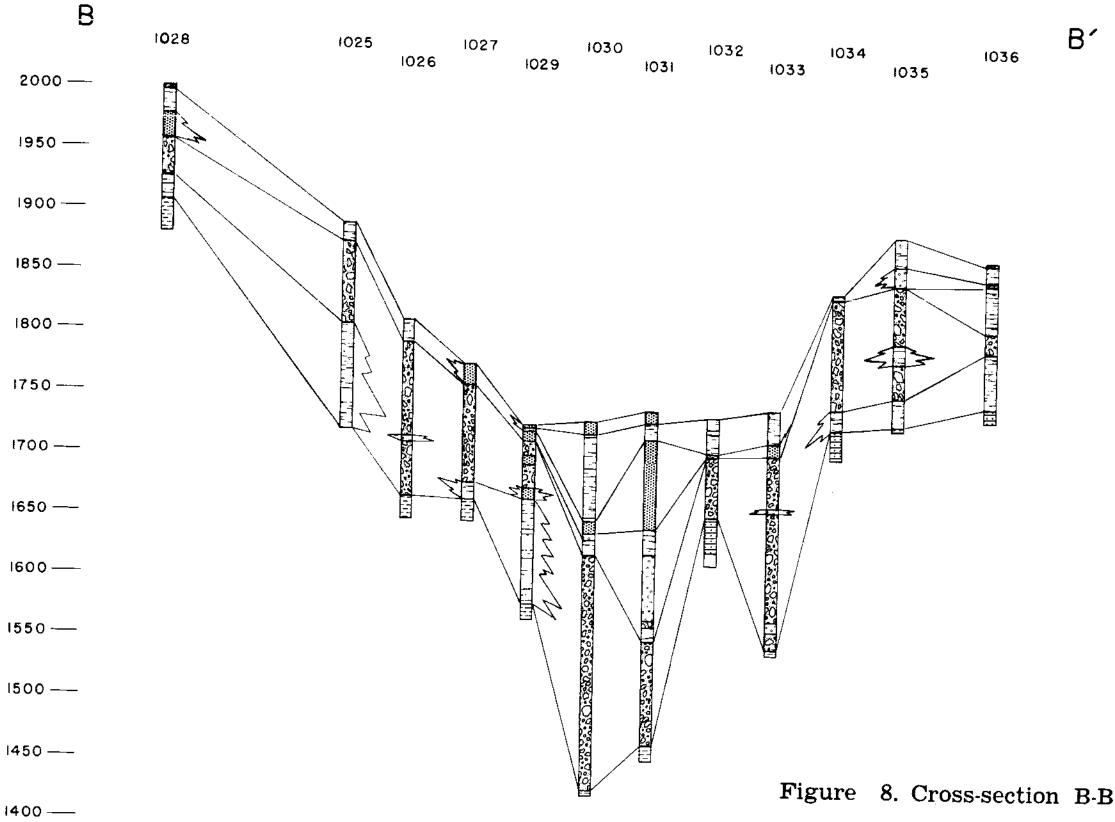


Figure 8. Cross-section B-B'.

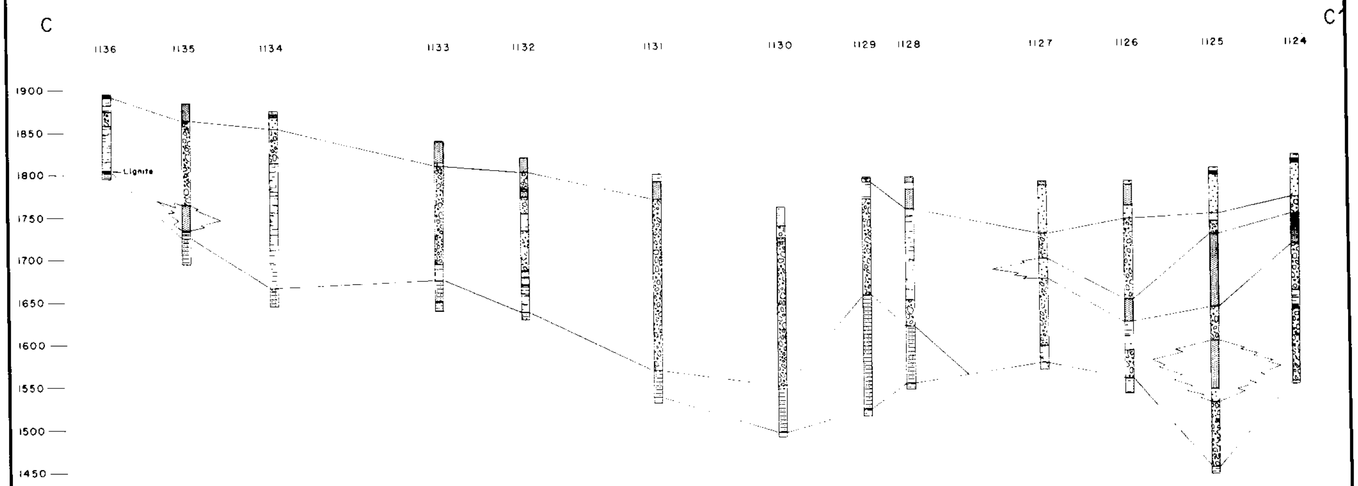


Figure 9. Cross-section C-C'.

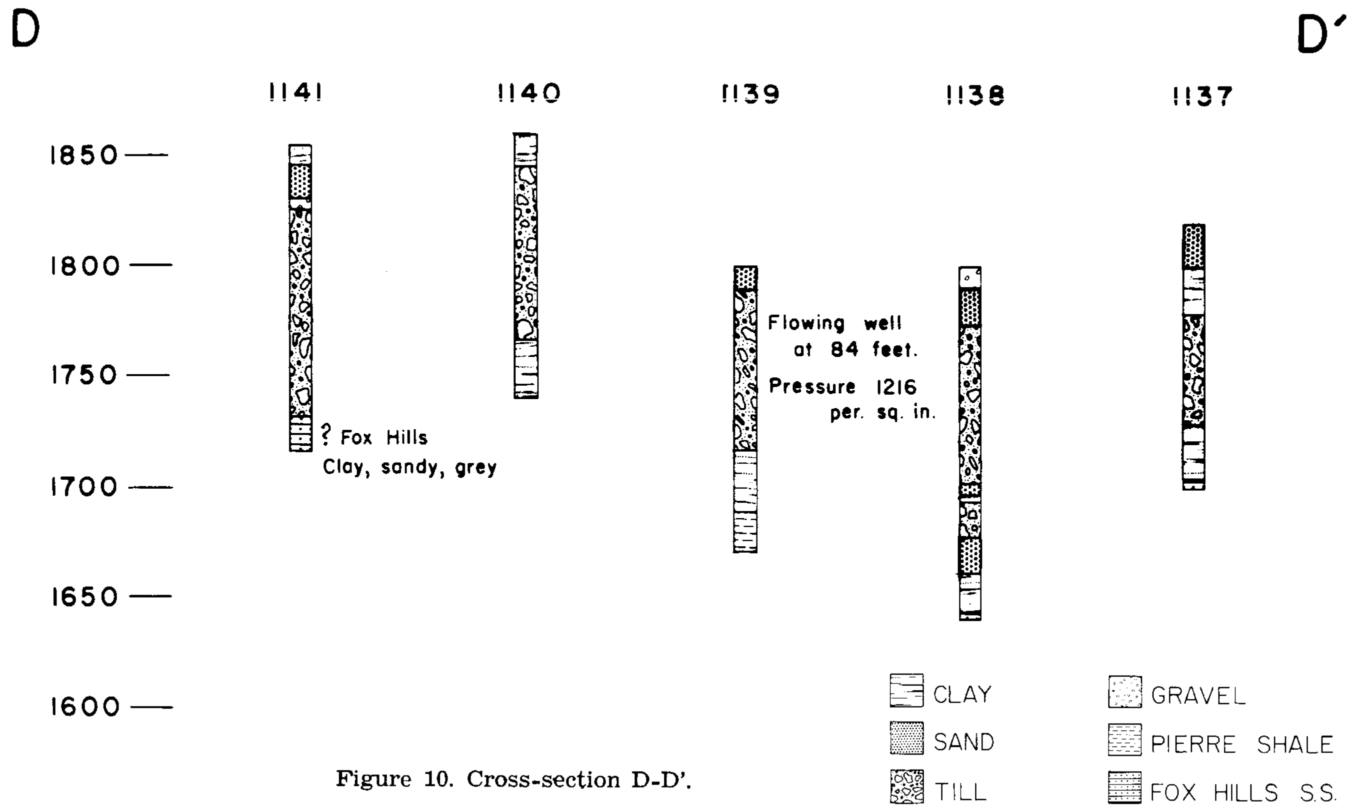


Figure 10. Cross-section D-D'.

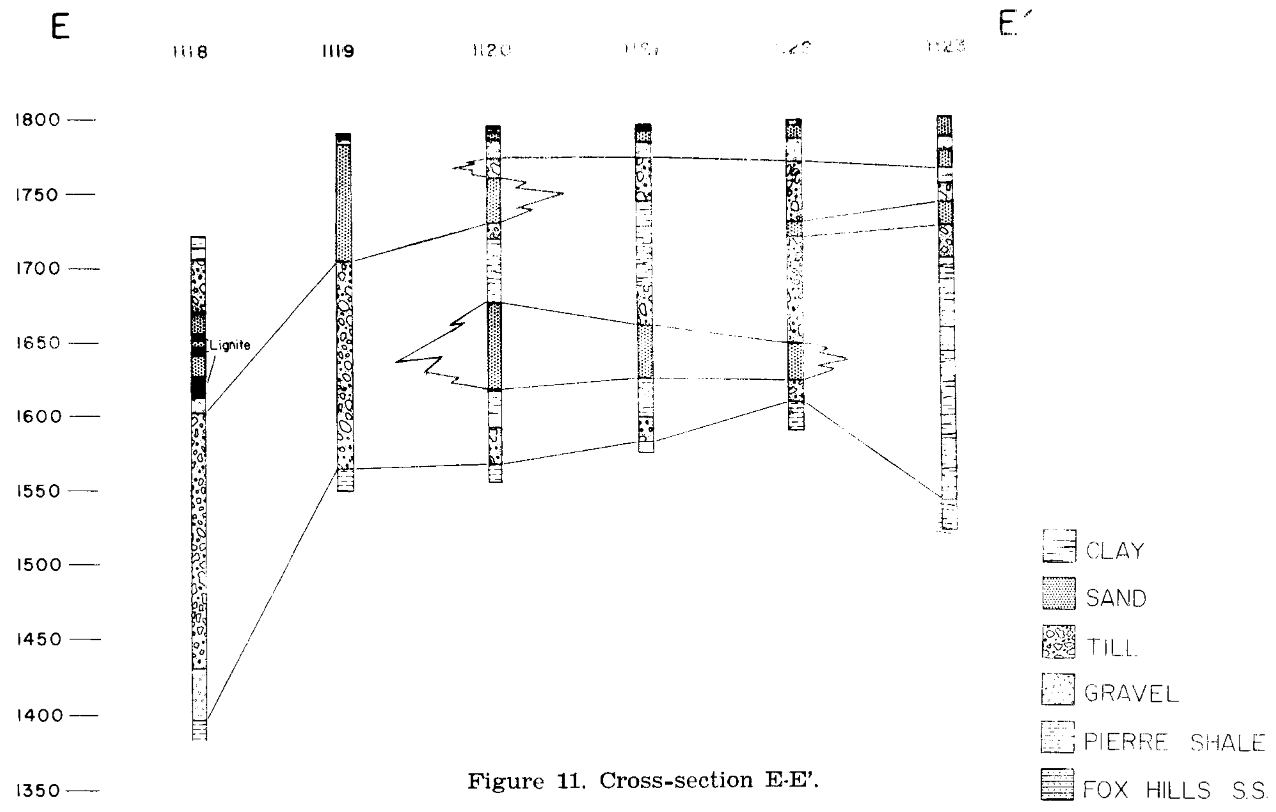


Figure 11. Cross-section E-E'.

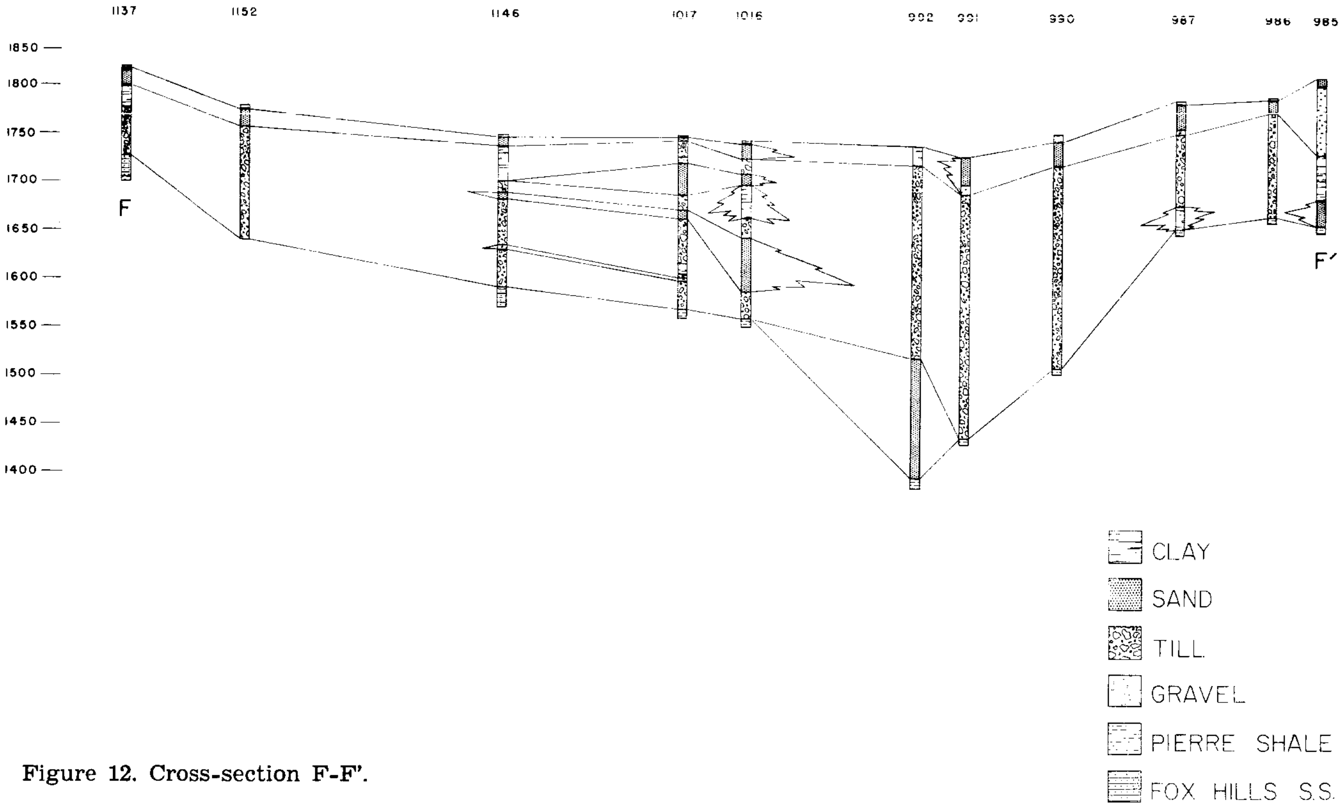


Figure 12. Cross-section F-F'.

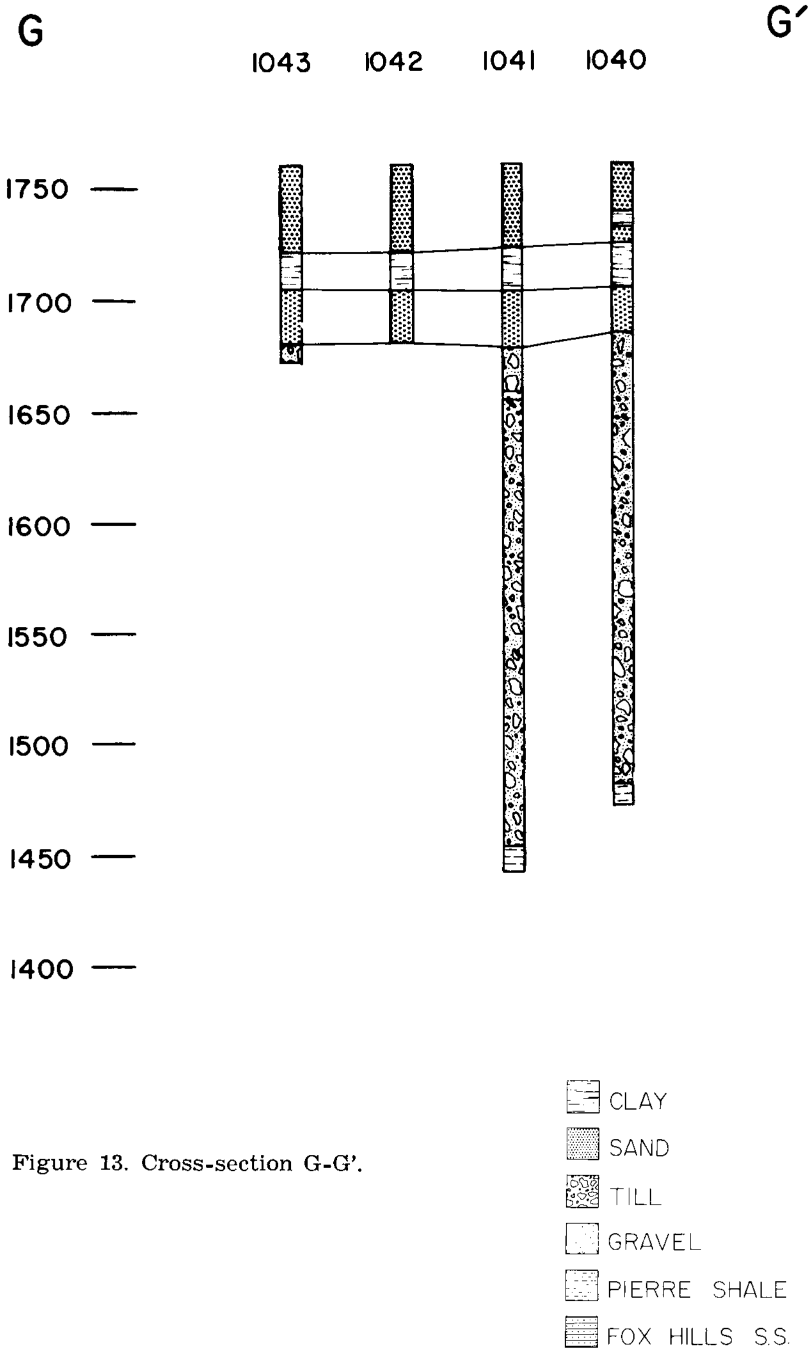


Figure 13. Cross-section G-G'.

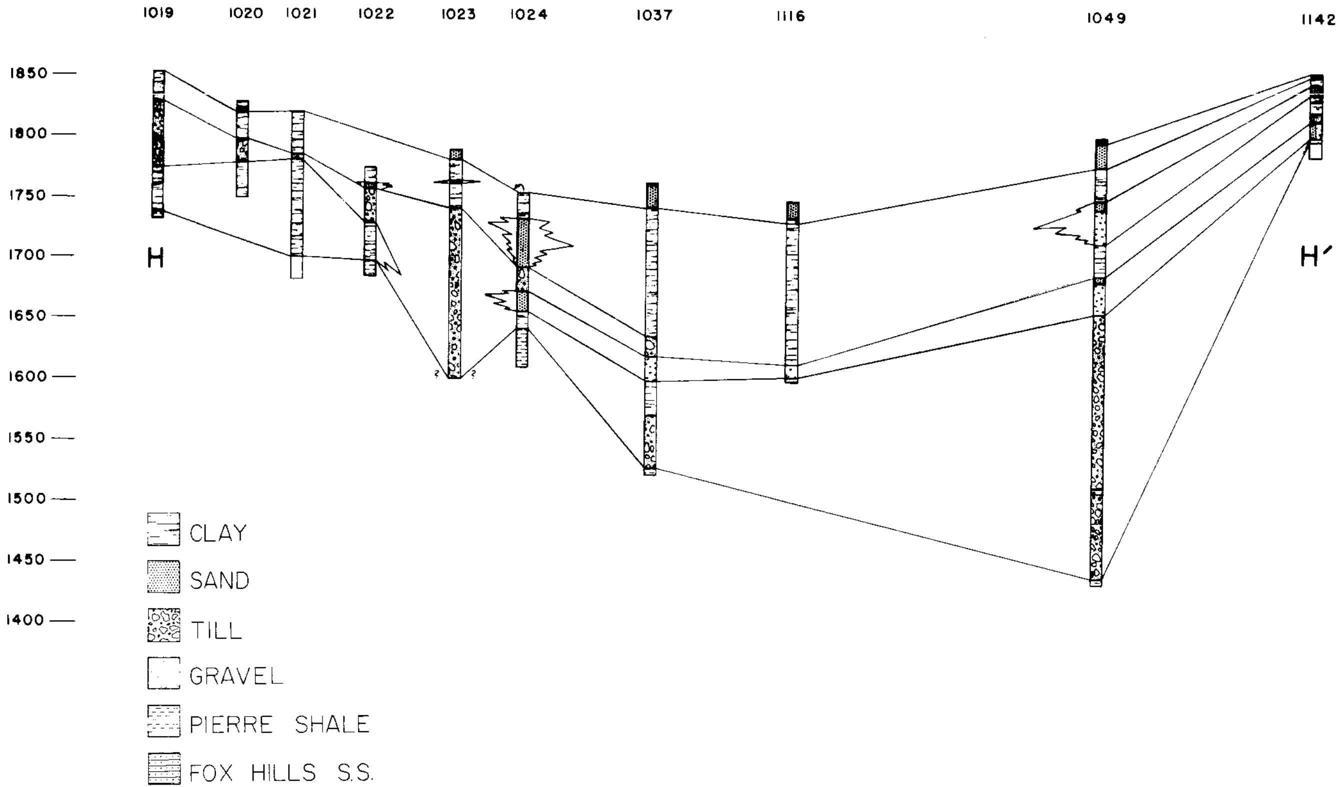


Figure 14. Cross-section H-H'.

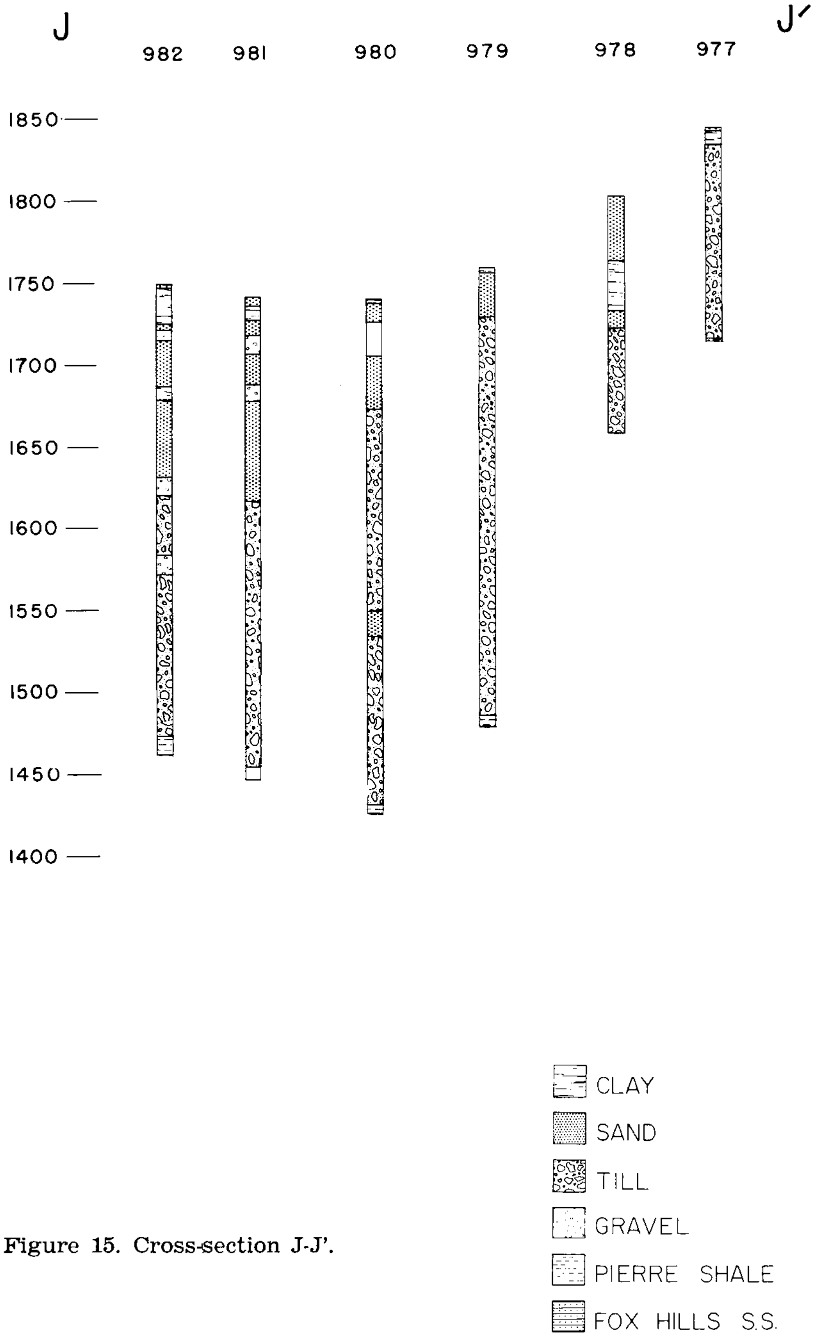


Figure 15. Cross-section J-J'.

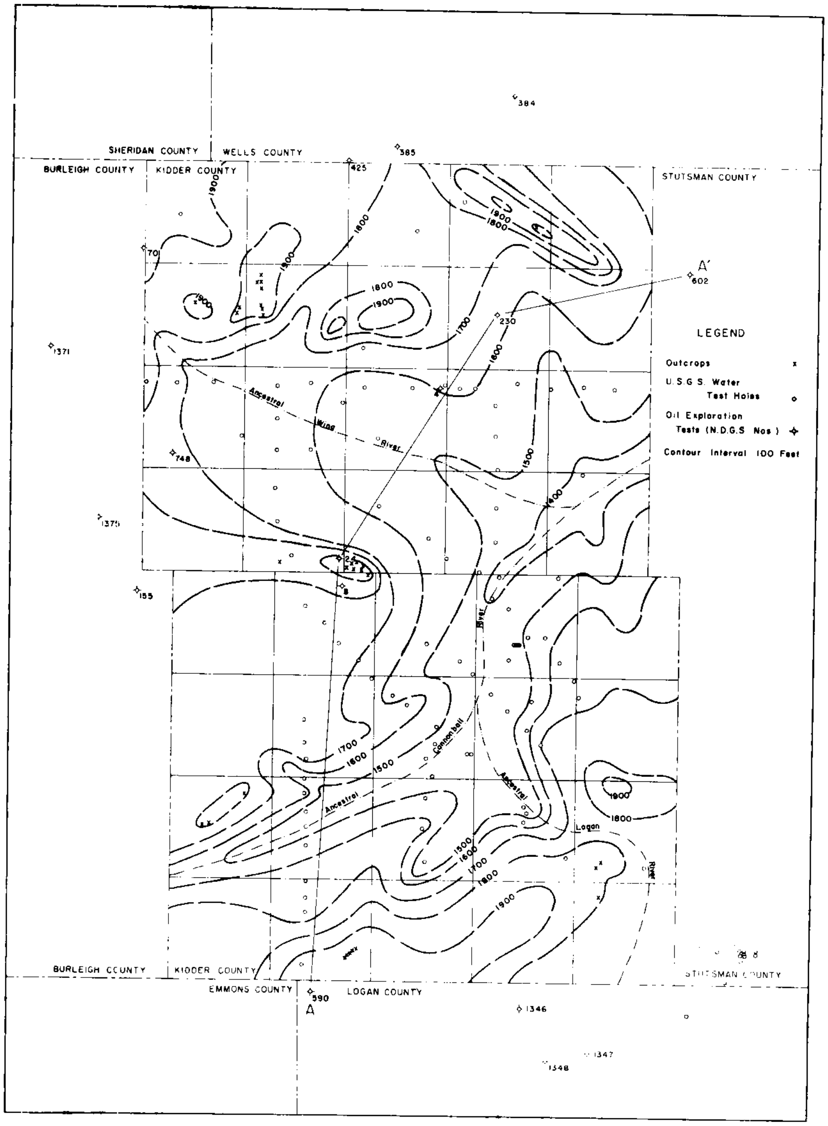


Figure 16. Contour map of bedrock surface under the glacial deposits of Kidder County showing courses of pre-glacial drainage.

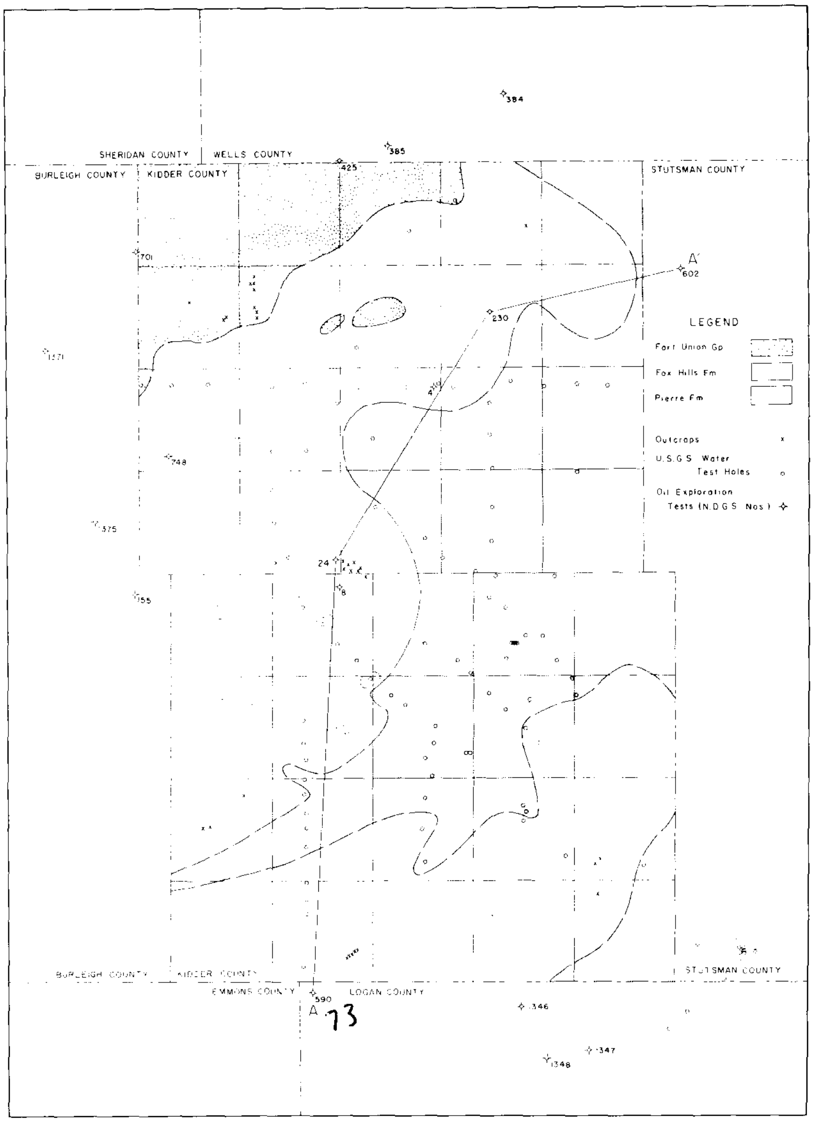


Figure 17. Geologic map of bedrock surface under the glacial deposits of Kidder County.

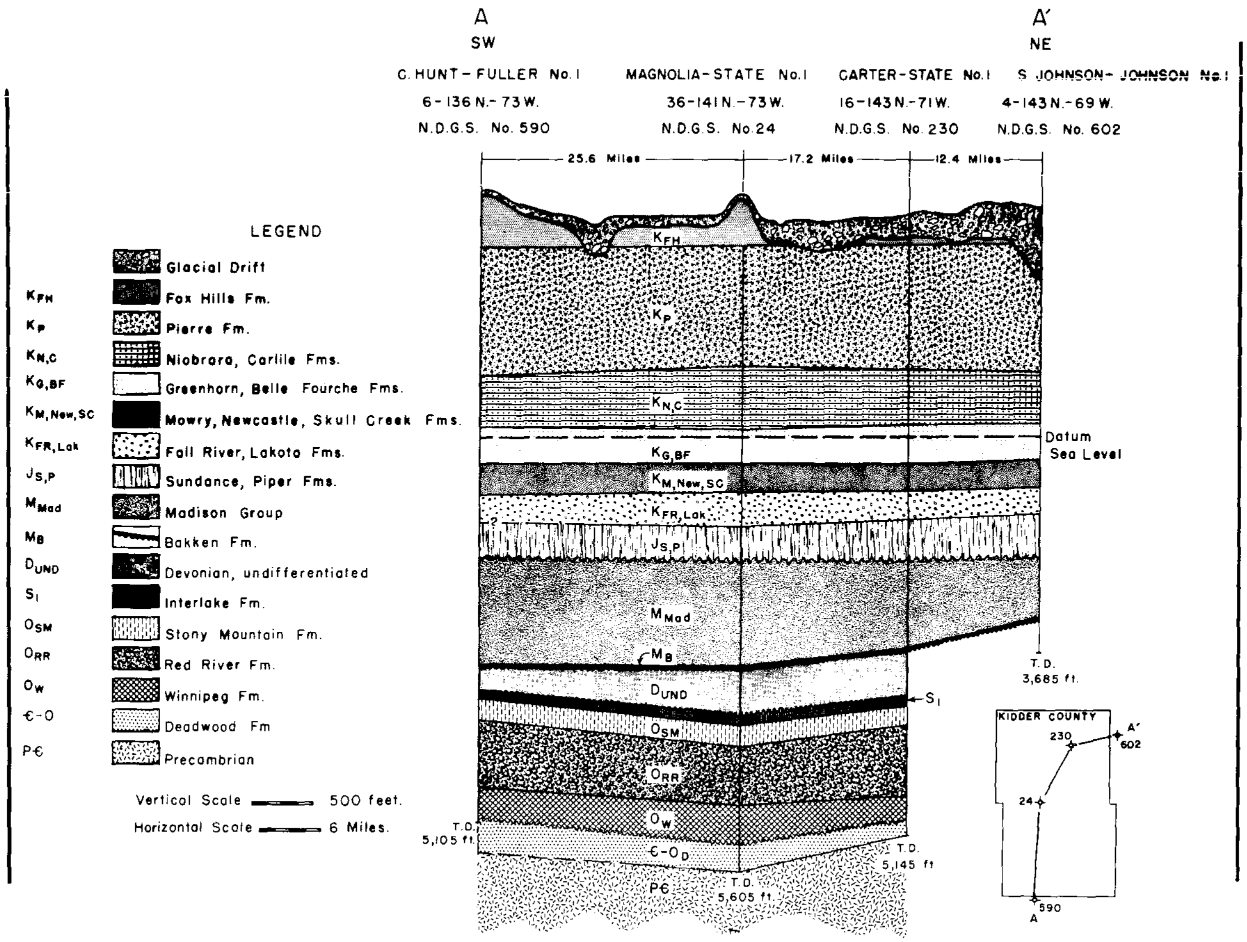
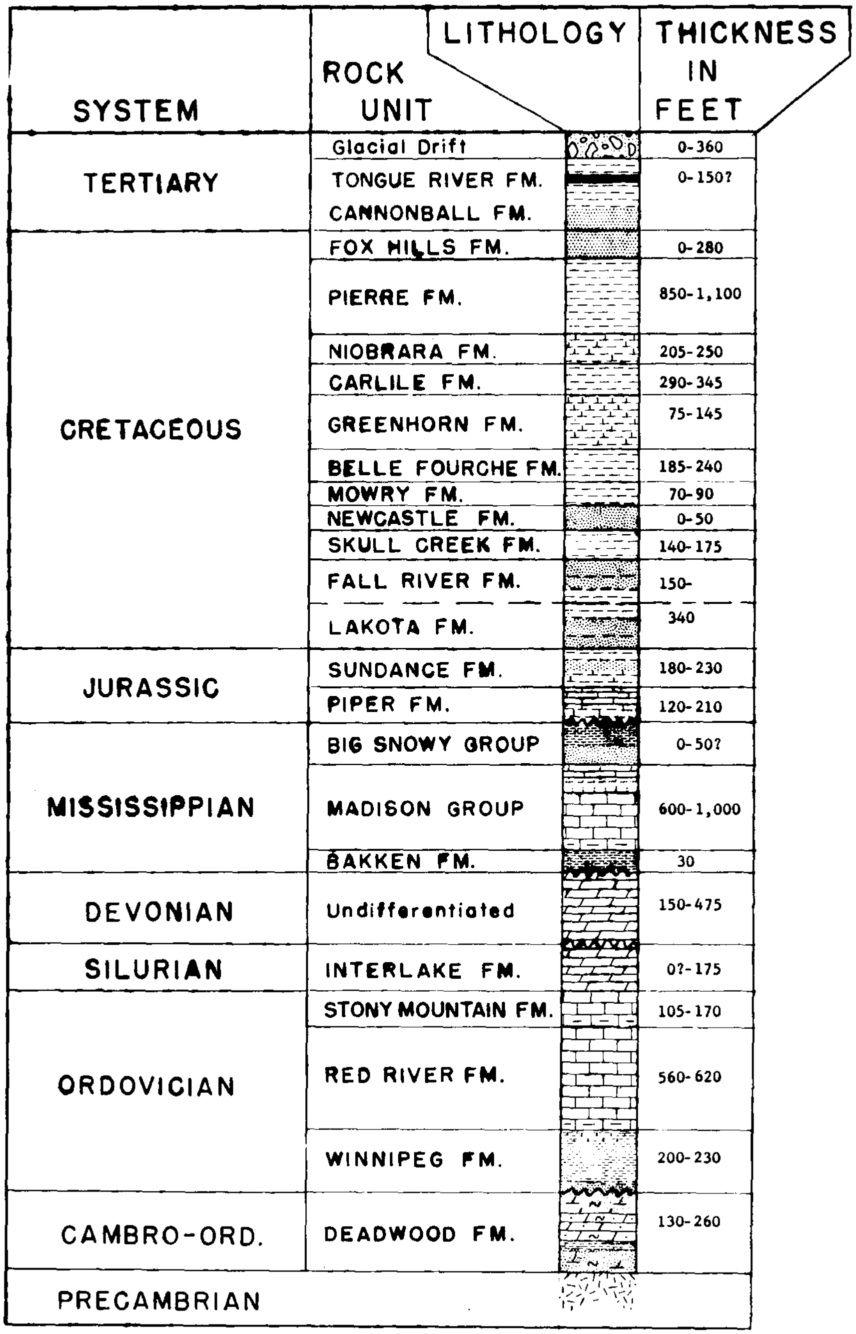


Figure 18. Kidder County bedrock cross-section.



SYSTEM	ROCK UNIT	LITHOLOGY	THICKNESS IN FEET
TERTIARY	Glacial Drift		0-360
	TONGUE RIVER FM.		0-150?
	CANNONBALL FM.		
CRETACEOUS	FOX HILLS FM.		0-280
	PIERRE FM.		850-1,100
	NIOBRARA FM.		205-250
	CARLILE FM.		290-345
	GREENHORN FM.		75-145
	BELLE FOURCHE FM.		185-240
	MOWRY FM.		70-90
	NEWCASTLE FM.		0-50
	SKULL CREEK FM.		140-175
	FALL RIVER FM.		150-
	LAKOTA FM.		340
JURASSIC	SUNDANCE FM.		180-230
	PIPER FM.		120-210
MISSISSIPPIAN	BIG SNOWY GROUP		0-50?
	MADISON GROUP		600-1,000
	BAKKEN FM.		30
DEVONIAN	Undifferentiated		150-475
SILURIAN	INTERLAKE FM.		0?-175
ORDOVICIAN	STONY MOUNTAIN FM.		105-170
	RED RIVER FM.		560-620
	WINNIPEG FM.		200-230
CAMBRO-ORD.	DEADWOOD FM.		130-260
PRECAMBRIAN			

Figure 19. Kidder County

LITHOLOGIC DESCRIPTIONS

Morainal, delta, and outwash deposits, lake beds and valley fill.

Shale, calcareous, light to dark colored; lignite and sandstone.
Cannonball formation: Marine sands, sandstone, clays and shales.

Sandstone, brown to gray; ironstone concretions; sandy shales and siltstones.

Shale, light to medium gray; ironstone concretions; some thin beds of bentonite.

Shale, calcareous, medium light gray to medium gray; contains calcareous "white specks".

Shale, medium dark gray to dark gray.

Shale, calcareous, soft, dark gray; Contains Inoceramus fragments and Globigerina.
Contains calcareous "white specks".

Shale, micaceous, medium dark gray to dark gray; bentonite, white to light blue gray.

Shale, flaky, soft, medium gray to dark gray, bentonitic.

Sandstone, quartzose, silty and shaly, light gray.

Shale, soft, medium to dark gray.

Sandstone, fine to coarse, quartzose, light gray; shale, silty, lumpy, gray.

Sandstone, medium to coarse, angular to subrounded, quartzose. Often contains light brown iron carbonate siltstone spherulites (pellets) and gray shale streaks.

Shale, light greenish gray, pale reddish brown; sandstone, fine grained, glauconitic; occasional limestone.

Limestone, dense, yellow gray; anhydrite; shale, grayish red, calcareous.

Siltstone and shale, reddish; sandstone, fine to medium grained, rounded, reddish.

Upper: Limestone, yellowish gray to pale red, oolitic, chalky and sucrosic; interbedded with white to pink anhydrite.
Lower: Limestone, light gray to light brownish gray, fragmental, fossiliferous.

Shale, medium dark gray.

Dolomites, light brownish gray to pale red, sucrosic.

Dolomite, very pale orange to pale red, finely crystalline.

Limestone, light gray to pinkish gray, fragmental, argillaceous in lower part.

Limestone, granular to dense, yellow gray, brownish gray; dolomite, similar to the limestone in appearance.

Shale, waxy, green to gray; sandstone, fine to medium grained, rounded to subrounded, quartzose, friable.

Sandstone, grayish orange pink, fine to medium grained, calcareous, glauconitic;
Dolomite, grayish pink, sandy, glauconitic.

Syenite, orange pink.

stratigraphic column.

Table I. Location and size composition of 47 samples of till. (After Clayton, 1960)

No.	Location	Percent Sand	Percent Silt	Percent Clay
C1-2	NE corner sec. 2, T. 138 N., R. 70 W.	36.8	25.5	37.7
C1-9	0.2 mi. N. of SE corner sec. 33, T. 138 N., R. 72 W.	27.8	30.7	41.5
C1-10-A	0.3 mi. N. of SE corner sec. 16, T. 137 N., R. 72 W.	31.0	38.5	30.5
C1-10-B	do.	25.0	45.0	30.0
C1-10-C	do.	34.4	35.0	30.6
C1-20	0.4 mi. N. of SW corner sec. 22, T. 141 N., R. 74 W.	30.8	30.4	38.8
C1-21-A	0.2 mi. S. of NE corner sec. 5, T. 141 N., R. 74 W.	57.5	13.3	29.2
C1-30	NE corner sec. 2, T. 137 N., R. 72 W.	28.2	35.4	36.4
C1-31	0.2 mi. N. of SE corner sec. 2, T. 137 N., R. 72 W.	28.3	31.7	40.0
C1-36	0.2 mi. S. of NW corner sec. 21, T. 138 N., R. 71 W.	25.4	27.8	46.8
C1-37-A	0.3 mi. N. of SW corner sec. 22, T. 138 N., R. 71 W.	48.1	21.8	30.1
C1-37-B	do.	36.2	30.8	33.0
C1-37-E	do.	28.4	28.4	43.2
C1-40	0.1 mi. N. of SE corner sec. 25, T. 138 N., R. 72 W.	55.9	25.2	18.9
C1-47-B	0.2 mi. S. of NW corner sec. 32, T. 139 N., R. 70 W.	26.1	43.6	30.3
C1-48-A	0.3 mi. S. of NE corner sec. 19, T. 138 N., R. 70 W.	47.0	25.1	27.9
C1-49	0.5 mi. W. of NE corner sec. 34, T. 138 N., R. 70 W.	28.0	29.4	42.6
C1-50	NE corner sec. 4, T. 137 N., R. 70 W.	26.0	30.4	43.6
C1-51	0.2 mi. N. of SE corner sec. 16, T. 137 N., R. 70 W.	27.5	31.1	41.4
C1-53	0.4 mi. N. of SE corner sec. 21, T. 137 N., R. 71 W.	24.8	29.7	45.5
C1-54	SW corner sec. 10, T. 137 N., R. 71 W.	28.3	37.5	34.2
C1-55	0.3 mi. S. of NW corner sec. 36, T. 140 N., R. 70 W.	41.3	35.3	23.4
C1-56	0.3 mi. S. of NE corner sec. 23, T. 140 N., R. 70 W.	43.0	34.6	22.4
C1-57	0.5 mi. N. of SE corner sec. 9, T. 140 N., R. 70 W.	28.0	27.0	45.0
C1-60	0.1 mi. N. of SW corner sec. 26, T. 141 N., R. 70 W.	7.9	53.8	38.3
C1-61	0.4 mi. S. of NW corner sec. 16, T. 141 N., R. 70 W.	24.0	33.0	42.1
C1-85-A	0.4 mi. N. of SW corner sec. 33, T. 139 N., R. 73 W.	1.0	22.0	77.0
C1-87	NE corner sec. 26, T. 140 N., R. 74 W.	25.7	29.4	44.9
C1-89	0.4 mi. N. of SW corner sec. 16, T. 140 N., R. 74 W.	38.7	29.4	31.9
C1-90	0.3 mi. E. of SW corner sec. 1, T. 140 N., R. 74 W.	29.2	30.1	40.7
C1-94	0.4 mi. W. of SE corner sec. 10, T. 139 N., R. 73 W.	25.0	34.8	40.2
C1-97	0.5 mi. W. of SE corner sec. 18, T. 141 N., R. 70 W.	33.8	33.0	33.2
C1-100	0.1 mi. N. of SW corner sec. 18, T. 142 N., R. 71 W.	38.6	34.3	33.1
C1-101	0.2 mi. E. of SW corner sec. 10, T. 141 N., R. 73 W.	58.5	21.5	20.0
C1-103	0.3 mi. N. of SW corner sec. 2, T. 140 N., R. 71 W.	34.4	29.9	35.7
C1-104	0.2 mi. N. of SW corner sec. 32, T. 139 N., R. 70 W.	32.7	29.8	37.5
C1-105	0.2 mi. E. of SW corner sec. 7, T. 139 N., R. 70 W.	39.5	27.0	33.5
C1-107	SE corner sec. 15, T. 137 N., R. 74 W.	35.6	32.2	32.2
C1-108	SE corner sec. 34, T. 137 N., R. 74 W.	27.4	42.3	30.3
C1-109	SE corner sec. 18, T. 137 N., R. 73 W.	31.4	29.6	39.0
C1-112	0.5 mi. N. of SE corner sec. 23, T. 139 N., R. 74 W.	27.0	37.2	35.8
C1-113	0.5 mi. W. of SE corner sec. 2, T. 138 N., R. 74 W.	26.5	39.1	34.4
C-71	NW ¼ sec. 4, T. 144 N., R. 70 W.	25.0	26.7	48.3
C-76	SE ¼ NE¼ sec. 32, T. 145 N., R. 74 W.	40.5	24.8	34.7
C-97	SE corner sec. 19, T. 143 N., R. 70 W.	38.6	24.4	37.0
C-106	0.6 mile S. of NW corner sec. 35, T. 144 N., R. 70 W.	28.9	29.8	41.3
-114	SE ¼ SE ¼ sec. 30, T. 144 N., R. 74 W.	46.2	29.8	24.0

APPENDIX I

Definitions of Terms

abrasion—Abrasion is the wearing away by rubbing or friction, the chief agents being currents of water laden with sand and other rock debris and by glaciers (Howell, et al., 1957, p. 1).

alluvium—Alluvium is a general term for all detrital deposits resulting from the operations of modern rivers, thus including the sediments laid down in river beds, flood plains, lakes, fans at the foot of mountain slopes, and estuaries (Howell, et al., 1957, p. 8).

Altamont moraine—A large end moraine complex in northeastern South Dakota which can be traced into the Mankato drift at Mankato, Minnesota. This same drift complex makes a prominent northwest trending end moraine extending from south-central to northwestern North Dakota. This moraine complex is characterized by hummocky moraines and associated ground moraine (Lemke and Colton, 1958) which show little integration of drainage in contrast to the well integrated drainage established on the Tazewell (?) drift to the southwest.

bedrock—Bedrock is the more or less solid rock in place either at the surface or beneath superficial deposits of gravel, sand, or soil (Stokes and Varnes, 1955, p. 14).

boulder—A rock fragment, usually rounded, greater than 256 mm. in diameter (Pettijohn, 1957).

Burnstad moraine—An end moraine extending from south-central Kidder County into northwestern McIntosh County.

carbon 14—"the ratio of the most common carbon isotope (C-12) to the least common isotope (C-14)." The fixed carbon ratio is the ratio of fixed carbon in any coal to the fixed carbon plus the volatile hydrocarbons, expressed in percentage (Lahee, 1952, p. 286).

Central lowland—A physiographic area covering wholly or parts of 16 states and including the low featureless plains of the central United States and extending over some 585,000 square miles. Glaciation dominates most of the landscape. In the north, the Central Lowland is limited on the west by the Great Plains province, an area in which remnants of a higher level remain as mesas and buttes in western North Dakota. Its eastern boundary is poorly marked in northeastern Minnesota, where the drift is very thick.

clay—an aggregate of mineral or rock material in which the individual particles are less than 1/256 mm. in diameter (Pettijohn, 1957). Clay is also used as a rock term, i.e., a natural plastic earth composed of hydrous alumina silicates.

cobble—"a rock fragment between 64 and 256 mm. in diameter, rounded or otherwise abraded in the course of aqueous, eolian, or glacial transport." (Howell, et al., 1957, p. 34).

Coteau du Missouri—That part of the Missouri Plateau sections of the Great Plains province which lies east of the Missouri River (Flint, 1955).

crescentic mark—Lunate marks on the bedrock surface formed by rocks embedded in the base of the overriding glacier (Flint, 1957).

dead-ice moraine—This moraine, sometimes spoken of as ablation moraine, is let down on to the ground as the thin enclosing ice melts inward from terminus, top, and base, and hence is loose, non-compact, and nonfissile, and probably lacks a fabric (Flint, 1957).

deflation—Deflation is the removal of material from a beach or other land surface by wind action (Howell, et al., 1957, p. 75).

drift—A term introduced by C. Lyell and widely used today, though without the early implication that it was "drifted" by water or floating ice. It is a genetic name for accumulations referable directly or indirectly to the Pleistocene ice. It comprises much of the loose and incoherent superficial deposits, such as clays, sands, and gravels, in glaciated countries (Charlesworth, 1957).

end moraine—This term has always connoted the concept of accumulation at the outer margin of a glacier. The concept was implicit in the original description by Agassiz (1840) who referred to the feature as "terminal moraine", regarded it as superglacial, and apparently thought of it as accumulated at the terminal margin rather than at the lateral margins of a valley glacier. Taking into consideration the history of the term, Flint (1955) used the following definition: "An end moraine is a ridgelike accumulation of drift built along any part of the margin of a valley glacier or an ice sheet."

eolian—Eolian refers to a feature of, relating to, formed by, or deposited from the wind or currents of air (Howell, **et al.,** 1957, p. 97).

epoch—An epoch is a subdivision of a period. The term is applied primarily to a major subdivision, but is likewise used for any subordinate unit, except for the subdivisions of the Pleistocene (Ashley, **et al.,** 1939, p. 1087).

esker—A sinuous, narrow ridge of drift which is believed to represent filling of a glacial stream channel (Thornbury, 1954).

formation—A formation is the fundamental unit in the local classification of rocks. It is a genetic unit which may represent a long or a short period of time, which may be composed of materials from different sources, and which may include minor breaks in the sequence (Ashley, **et al.,** 1939, p. 1074-1075).

frequency curve—A smooth curve drawn through the tops of the vertical bars of a histogram.

granule—A term proposed by Wentworth (1922) for mineral or rock material from 2 to 4 mm. in diameter (Pettijohn, 1957). Pettijohn (1957, p. 20) in a footnote states that the committee on sedimentation omitted using this term and granule now appears to be abandoned as a size term.

groove—A line on the bedrock surface, deeper than a striation, believed inscribed by rocks imbedded in the base of the ice sheet; "the terms 'grooving' and 'striation' are often used synonymously, and, within certain limits, properly enough, since it is impossible to draw any sharp line of distinction between them." (Howell, **et al.,** 1957, p.   ).

ground moraine—Moraine having low relief devoid of transverse linear elements (Flint, 1957).

histogram—A vertical bar graph representing the size composition of a sediment with the area of the bars being proportional to the quantity of the material in each class. The width of the bars is determined by the class limits (Pettijohn, 1957).

ice-contact feature—An ice-contact feature is stratified drift built in immediate contact with wasting ice. These features include eskers, kame terraces, kames, and features marked by numerous kettles (Flint, 1957, p. 136).

interstadial—Glacial stages are subdivided in substages separated by subintervals or interstadials (Thwaites, 1946, p. 58).

kame—"A mound of stratified drift deposited in contact with a glacier by streams of sediment-laden meltwater flowing off the ice sheet." (Howell, **et al.,** 1957).

kame terrace—A term proposed by Salisbury (1893) for an accumulation of drift deposited between a glacier and a valley wall. They commonly occur in pairs along opposite sides of a valley and are a constructional type of terrace (Flint, 1957).

kettle—"A depression in drift formed by wastage of a detached mass of glacial ice that was either buried or partly buried in the drift." (Howell, **et al.**, 1957)

kettle chain—Groups of kettles occurring in a linear pattern.

lacustrine—"Lacustrine refers to a feature of, pertaining to, formed or growing in, or inhabiting lakes." (Howell, **et al.**, 1957, p. 161).

lithology—The megascopic examination of rocks and their description (Howell, **et al.**, 1957). Its root words strictly mean the study of rocks.

lobe—A lobe is a projection of a glacial margin or of a body of glacial drift beyond the main mass of ice or drift (Howell, **et al.**, 1957, p. 172).

loess—Loess is a sediment, commonly nonstratified and commonly unconsolidated, composed dominantly of silt-size particles, ordinarily with accessory clay and sand, and deposited primarily by the wind (Flint, 1957, p. 181).

Max moraine—The Max moraine is a series of northwest trending morainic hills in northwestern North Dakota. It extends for 800 miles and forms a divide between northeastward drainage to the Hudson Bay area and southwestward drainage to the Missouri River (Townsend and Jenke, 1951).

Missouri Plateau—The rock surface in the western part of the Dakotas which slopes gently east. It rises from 300 feet at the south, west of the lower James River Valley, to 600 to 700 feet at the north. It therefore marks the eastern portion of the Great Plains province in North Dakota and is partially mantled by glacial drift there.

moraine—The term "moraine" is of French origin, but its exact derivation is uncertain. It appeared in the literature as early as 1777 (Boehm, 1901) and in the clear descriptions of Saussure (1786-1796) it carried a topographic implication. Moraine can be defined as an accummulation of drift having a constructional topographic expression in detail that is independent of the surface of the ground underneath it, and having been built by the direct action of glacial ice (Flint, 1955).

outwash—Outwash is stratified drift that is stream built ("washed out") beyond the glacier itself (Flint, 1957, p. 136).

outwash channel or meltwater channel—An outwash channel is a stream channel formed by a proglacial stream that led away from the former ice sheet (Thwaites, 1946, p. 54).

pebble—A rock fragment ranging from 4 to 64 mm. in diameter which has been abraded and rounded by the action of wind, water, or glacial ice (Pettijohn, 1957).

period—A period is the fundamental unit of the standard geologic time scale. It is the time during which a standard system of rocks was formed (Ashley, **et al.**, 1939, p. 1087).

Pleistocene—A term introduced by Charles Lyell (1839) for the most recent geologic time interval spanning the last million years of geological history. He originally used it as a subdivision of the Pliocene epoch. Forbes (1846) applied Pleistocene to the "Glacial epoch" or the time of the Great Ice Age and set it aside as a separate time term represented by rocks of more recent age than Pliocene. Lyell (1873) accepted this restriction and Pleistocene has been used since to designate the post-Pliocene time interval. The United States Geological Survey and the North Dakota Geological Survey recognize the Pleistocene as a separate epoch of the Quaternary period.

plucking—"A type of glacial erosion whereby blocks of bedrock are removed along joints and stratification surfaces." (Howell, **et al.,** 1957).

radiocarbon date—"The absolute age of a material as determined by measuring the proportion of the isotope C-14 in the carbon it contains. It is not reliable for determination of ages greater than 30,000 years." (Howell, **et al.,** 1957).

recessional moraine—Closely bunched narrow linear moraines built up during glacial shrinkage. These moraines show relatively little of the abrupt hummock and kettle topography which is so common in the end moraine complexes.

sand—An aggregate of mineral or rock grains ranging between 1/16 mm. to 1/256 mm. in diameter (Pettijohn, 1957).

sediment—Material in suspension in water or recently deposited from the waters of streams, lakes, or seas (Bryan, 1922, **in** Howell, **et al.,** 1957). In general, the deposits of wind, water, and ice.

silt—An aggregate of mineral or rock grains ranging from 1/16 mm. to 1/256 mm. in diameter (Pettijohn, 1957).

soil profile—A soil profile is a vertical section of the soil from the surface through all its horizons into the parent material (Howell, **et al.,** 1957).

spillway—A spillway is an overflow channel or an outlet of a glacial lake. It is excavated in rock or drift and has sharp edges at top and bottom (Charlesworth, 1957, p. 459).

stage—A stage is a subdivision of a series. It is the body of strata deposited during an age (Krumbein and Sloss, 1951, p. 24-25).

strandline—That portion of the shore between high and low tide.

striation—A fine cut line on the bedrock surface believed inscribed by the rock particles imbedded in the base of the overriding glacier (Flint, 1957).

stratified drift—Stratified drift is drift exhibiting both sorting and stratification, implyng deposition from a fluid medium such as water or air (Howell, **et al.,** p. 281).

Streeter moraine—An end moraine extending from southern Wells County through Kidder County southeastward into Logan and McIntosh counties.

substage—A substage is a subdivision of a stage (Dunbar and Rodgers, 1957, p. 299).

inwash—Nonglacial alluvium mingled with glacial outwash or accumulated in contact with a glacier. Such material is typically exposed in eastern Nebraska (Flint, 1957).

terrace—"A relatively level-topped surface with a steep escarpment." (Howell, **et al.,** 1957).

terminal moraine—An end moraine built along the downstream or terminal margin of any glacier lobe.

till—Generally fine-grained unstratified and unsorted ice-laid material (Pettijohn, 1957).

Two Creeks interstadial—Interstadial between the Cary and Mankota-Valders substages. During this time, the ice melted away from the Straits of Mackinac, so that most of the Great Lakes region was ice free. Uncovering of the straits afforded a new outlet for Lake Chicago, which was lowered below the present level of Lake Michigan, so recorded by the spruce-bog peat exposed at Two Creeks, Wisconsin, whence the name of the interstadial. During the Two Creeks time interval, an erosional period occurred in the Lake Agassiz area and the lake was completely drained, according to Elson (1958).

unconformity—A surface of non-deposition or erosion. Shrock (1948, p. 25) states that unconformity is the relationship between overlying rock bodies such that the older has eroded before the younger was deposited over it.

ventifact—A ventifact is a stone shaped by the abrasive action of wind-blown sand (Howell, **et al.**, 1957, p. 313).

washboard moraine—Moraine having a washboard appearance.

water table—In previous granular material the water table is the upper surface of the body of free water which completely fills all openings in material sufficiently pervious to permit percolation. In fractured impervious rocks and in solution openings, it is the surface at the contact between the water body in the openings and the overlying ground air (Tolman, 1937, p. 565).

Western Lake district—A part of the Central Lowland province which includes portions of eastern North Dakota and western Minnesota.

Wisconsin drift—This drift was named by T. C. Chamberlin in the Central Lowland region. He originally called it East-Wisconsin, but soon shortened the name to its present form. As the term was understood by Chamberlin, it did not embrace all the drift now included in the Wisconsin Sage. It excluded the Iowan drift in most areas and excluded both Iowan and Tazewell drifts in some others. It has since been subdivided into four substages, each of which marks a conspicuous expansion of the Wisconsin ice sheet (Iowan substage, Tazewell substage, Cary substage, and Mankato substage). No more than two of the four Wisconsin substages are seen in contact in any one exposure, and few exposures show as many as two (Flint, 1955).

References

Ashley, G. H., **et al.** (Commission on Stratigraphic Nomenclature), 1939, Classification and nomenclature of rock units: Am. Assoc. Petroleum Geologists Bull., v. 23, p. 1068-1088.

American Society for Testing Materials, 1958, Nomenclature and definitions, standard methods, suggested methods: Philadelphia.

Bavendick, F. J., 1959, North Dakota: Climatography of the U. S., No. 60-32.

Bergman, H. F., 1912, Flora of North Dakota; Sixth Bienn. Rept., Soil Geol. Surv. of N. Dak., p. 151-372.

Campbell, M. R., and others, 1916, Guidebook of the western United States, Part A, The Northern Pacific Route: U. S. Geol. Survey, Bull. 611.

Chamberlin, T. C., 1883, Terminal moraine of the second glacial epoch: U. S. Geol. Survey Third Ann. Rept.

Charlesworth, J. K., 1957, The Quaternary era: London, Edward Arnold Publishers, Ltd., 2 vols., 1700 p.

Clayton, Lee, 1960, Tills of Kidder County, North Dakota, unpublished report in files of Department of Geology, University of North Dakota at Grand Forks.

Denny, C. S., 1936, Periglacial phenomena in southern Connecticut: Am. Jour. Science, v. 32, p. 322-342.

Dunbar, C. O., and Rodgers, John, 1957, Principals of stratigraphy: New York, Wiley and Sons, Inc.

Fenneman, N. M., 1930, Physical divisions of the United States (map): U. S. Geol. Survey.

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

Flint, R. F., 1942, Glacier thinning inferred from geologic data: Am. Jour. Science, v. 240, p. 113-136.

Flint, R. F., 1955, Pleistocene geology of eastern South Dakota: U. S. Geol. Survey Prof. Paper 262.

Flint, R. F., 1957, Glacial and Pleistocene geology: New York, Wiley and Sons, Inc.

——— and others, 1959, Glacial map of the United States east of the Rocky Mountains: Geol. Soc. America.

Frye, J. C., and Leonard, A. B., 1953, Definitions of time line separating a glacial and interglacial age in the Pleistocene: Am. Assoc. Petroleum Geologists Bull., v. 33, p. 853-862.

Frye, J. C., and Willman, H. B., 1960, Classification of the Wisconsinan Stage in the Lake Michigan glacial lobe: Illinois State Geological Survey, Circular 285.

Goddard, E. N., **et al.**, 1948, Rock-color chart: Geol. Soc. America.

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

Hard, H. A., and McKinstry, H., 1910, Soil survey of Dawson area, Kidder County, North Dakota: Agricultural Coll. Survey of North Dakota, 5th Bienn. Rept.

Howard, A. D., 1946, Till pebble isopleth maps of parts of Montana and North Dakota: Bull. Geol. Soc. America, v. 67, p. 1199-1206.

Howell, J. V., **et al.**, 1957, Glossary of geology and related sciences: Williams and Heintz Lithograph Corp., Washington, D. C.

Horberg, Leland, 1951, Intersecting minor ridges and periglacial features in the Lake Agassiz basin, North Dakota: Jour. Geology, v. 59, p. 1-18.

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

Krumbein, W. C., and Pettijohn, F. J., 1938, Manual of sedimentary petrography: New York, Appleton-Century-Crofts, Inc.

Krumbein, W. C., and Sloss, L. L., 1951, Stratigraphy and sedimentation: San Francisco, W. H. Freeman and Co.

Lamerson, P. R., and Dwellig, L. F., 1957, Deformation by ice push of lithified sediments in south-central Iowa: Jour. Geology, v. 65, p. 546-550.

Lapham, M. H., 1910, Soil survey of western North Dakota: U. S. Dept. Agric., Bur. of Soils.

Leighton, M. M., 1957, Radiocarbon dates of Mankato drift in Minnesota: Science, v. 125, p. 1037-1038.

Leighton, M. M., 1957, The Cary-Mankato-Valders problem: Jour. Geology, v. 65, p. 108-111.

Leighton, M. M., 1958, Important elements in the classification of the Wisconsin glacial stage: Jour. Geology, v. 66, p. 288-309.

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

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

———, and Kaye, C. A., 1958, Two tills in the Donnybrook area, North Dakota **in** Midwestern Friends of the Pleistocene, N. Dak., Guidebook, 9th Ann. Field Conf., p. 93-98.

Leonard, A. G., 1912, Geology of south-eentral North Dakota: Sixth Bienn. Rept., N. Dak. Geological Survey.

Leverett, F., 1932, Quaternary geology of Minnesota and part of adjacent states: U. S. Geol. Survey Prof. Paper 161.

Meek, F. B., and Hayden, F. V., 1876, Report of the. U. S. Geol. Survey of the Territories, v. IX.

Moir, D. R., 1957, An occurrence of buried coniferous wood in the Altamont moraine in North Dakota: Proc. of the North Dakota Acad. of Science, v. XI, p. 69-74.

Moir, D. R., 1958, Occurrence and radiocarbon date of coniferous wood in Kidder County, North Dakota: Guidebook, 9th Ann. Field Conf. Midwestern Friends of the Pleistocene, North Dakota, p. 108-114.

Paulson, Q. F., 1952, Geology and occurrence of ground water in the Streeter area, Stutsman, Logan, and Kidder counties, North Dakota: N. Dak. Ground Water Studies No. 20.

Roth, F. J., and Zimmerman. J. J., 1955, Physiography of North Dakota: The Compass of Sigma Gamma Epsilon, v. 32, p. 83-85.

Ruhe, R. V., and Rubin M., and Scholtes, W. H., 1957, Late Pleistocene radiocarbon chronology in Iowa: Am. Jour. Sci., v. 255, p. 671-689.

Schafer, J. P., 1949, Some periglacial features in central Montana: Jour. Geology, v. 57, p. 154-174.

Schmitz, E. R., 1955, Stream piracy and glacial diversion of the Little Missouri River, North Dakota: Unpublished Master's thesis, Univ. of North Dakota.

Sharp, R. P., 1942, Periglacial involutions in northeastern Illinois: Jour. Geology, v. 50, p. 113-133.

Sharp, R. P., 1951, Glacial history of Wolf Creek, St. Elias Range, Canada: Jour. Geology, v. 59, p. 97-117.

Shepps, V. C., 1953, Correlation of the tills of northeastern Ohio by size analysis: Jour. Sed. Petrology, v. 23, p. 34-48.

Stokes, W. L., and Varnes, D. J., 1955, Glossary of selected geologic terms: Denver, Colo., Colorado Scientific Society Proceedings, v. 16.

Thwaites, F. T., 1946, Outlines of glacial geology: Ann Arbor, Mich., Edwards Bros.

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

Tolman, C. F., 1937, Gound water: New York, McGraw-Hill, Inc.

Townsend, R. C., 1950, Deformation of Fort Union Formation near Lignite, North Dakota: Am. Assoc. Petroleum Geologist Bull., v. 34, p. 1552-1564.

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

United States Department of Agriculture, 1938, Soils and men.

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

Wood, R. L., 1959, Ice-pushed deformation in Shawnee County, Kansas: The Compass of Sigma Gamma Epsilon, v. 36, p. 304-309.

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

————, 1957, Radiocarbon dates of Mankato drift in Minnesota: Science, v. 125, p. 1038-1039.

————, and Rubin, M., 1956, Radiocarbon dates of Mankato drift in Minnesota: Science, v. 124, p. 625-626.

————, 1953, Geologic dating and the time scale of the ice age: Proc. Minnesota Acad. Sci., v. 21, p. 42-46.

SUBSURFACE GEOLOGY OF KIDDER COUNTY

By C. G. Carlson

Five wells have been drilled for oil in Kidder County as of November 1, 1960, and thirteen wells have been drilled within six miles of the boundaries of the county. The first of these was drilled in 1926 by the A. C. Townley Interests as the Robinson Patented Lands No. 1 well, located in Section 12, T. 142 N., R. 72 W., but no reliable information from that well is available. The Prairie Oil and Gas-Armstrong No. 1 well, located in Section 2, T. 140 N., R. 73 W., was drilled in 1929 to a total depth of 3,884 feet. Sample descriptions of the Armstrong well have previously been published (Laird, 1941, p. 23); however, these descriptions are from driller's logs and are rather sketchy. Samples and mechanical logs are available in the files of the North Dakota Geological Survey for three wells which have been drilled more recently in Kidder County. Descriptions of samples from these and a few other wells in the Kidder County area have previously been published (Strassberg, 1953; Caldwell, 1954; Smith, 1954 a, 1954 b; Hansen, 1959,). Some slight shows of oil have been reported from the Continental-Duemeland No. 1, located in section 3, T. 140 N., R. 77 W., and the Leach Calvert-Patterson Land Company No. 1, located in Section 11, T. 140 N., R. 77 W., Burleigh County, both of which had spotty staining in the Winnipeg Formation, but no commercial production has been found as yet.

The United States Geological Survey has drilled about 92 water test holes in Kidder County, and some water test holes in adjacent counties to the south and east of Kidder County. These water test holes and the oil test wells furnished the basis for an interpretation of the subsurface geology of Kidder County. The location of the oil test wells, for which North Dakota Geological Survey file numbers were used, and the water test holes are shown on the bedrock geologic map (Figure 17). The inferred contacts are based on the present surface topography and drilling data which provided information on the bedrock, thickness of drift, and subglacial topography.

The generalized stratigraphic section for Kidder County is shown by a cross-section (Figure 18) and the stratigraphic column (Figure 19). The lithologies are based on previously published sample descriptions, and the thicknesses were determined from mechanical logs.

Precambrian. The depth of the Precambrian ranges from about 2700 feet in southeastern Kidder County to about 4700 feet in northwestern Kidder County. The composition of the Precambrian rocks is not well known, since only four wells have penetrated Precambrian rocks in the Kidder County area. However, the Precambrian is composed of an orange-pink syenite in each of these wells.

Paleozoic. There are three unconformities within the Paleozoic rocks of this area. They are, in ascending order, (1) the unconformity between the Deadwood Formation of Upper Cambrian to Lower Orodvician age and the Winnipeg Formation of Middle Ordovician age; (2) the unconformity between the Interlake Formation of Silurian age and the Devonian rocks; and (3) the unconformity between Devonian rocks and the Bakken Formation of Mississippian age.

The Paleozoic formations are generally thickest in the northwestern part of the county and thin southeastward. The formational subdivision of the Upper Cambrian through Silurian rocks of Kidder County is the same as that used for the central part of the Williston Basin. However, no formational subdivision of the Devonian rocks of Kidder County was attempted, because it is very difficult to correlate this part of the geologic section with a similar but somewhat better known section in the deeper parts of the Williston Basin, where rocks of Devonian age are as much as 1,900 feet thick.

In the Williston Basin, the Madison Group has previously been divided into three formations, the Lodgepole, Mission Canyon and Charles. Later, as facies relationships were better understood, the Madison Group has been divided into intervals based on marker beds. However, in this report, the Madison Group is discussed as the Madison Group undifferentiated, rather than attempting to divide it into formations or intervals, because a major unconformity exists between the Paleozoic and Mesozoic rocks in this area. Thus the Big Snowy Group has been completely removed and the upper part of the Madison Group has been removed from Eastern Kidder County by pre-Middle Jurassic erosion. Furthermore, weathering of the Madison Group extends for about 300 feet below the post-Madison surface, with varying amounts of reddish coloration, recrystalization and dolomitization, so that the markers useful for subdivision of the Madison Group in other areas of the Williston Basin cannot be picked with certainty in Kidder County.

Mesozoic. The Piper formation, of Jurassic age, unconformably overlies the Mississippian rocks throughout this area, and is overlain conformably by the Sundance Formation. The contact between the Jurassic and Cretaceous Systems is difficult to trace in the subsurface, and is usually drawn at the base of a relatively thick sandstone bed at the base of the Lakota Formation.

The basal Cretaceous sediments are the Lakota-Fall River Formations, undifferentiated in the subsurface, consisting of interbedded sandstones and shales. Overlying the Fall River Formation is a thick, conformable sequence of Cretaceous rocks composed mostly of shale, with minor amounts of sandstone and siltstone. This sequence has been divided into nine formations which, in ascending order, are: Skull Creek, Newcastle, Mowry, Belle Fourche, Greenhorn, Carlile, Niobrara, Pierre, and Fox Hills. The thickness of these formations is somewhat variable, but the thickest sections are generally in the northwestern part of Kidder County, except for the Newcastle Sandstone, which has a tongue-like distribution with the thickest section in the southeastern part of the county.

The Pierre Formation is not exposed at any locality in Kidder County, but it is the bedrock in much of the eastern part of the county, so the thickness is quite variable in this area, because of unequal erosion in pre-glacial times. It becomes quite silty in the upper part, and is gradational into the overlying Fox Hills Formation. The Fox Hills Formation crops out at several localities in the southern and west-central parts of Kidder County, and is the bedrock in most of that part of the county. The contact between the Pierre and Fox Hills is difficult to determine in the subsurface, particularly where water test holes have penetrated only a few feet of bedrock. However, in most cases it can be determined with a fair degree of certainty.

Cenozoic. Rocks which have been mapped as the Cannonball and Tongue River Formations of the Fort Union Group crop out at several localities in the northwestern part of Kidder County. Lithologically, these rocks resemble the Tongue River Formation more closely than they do the Hell Creek Formation, but the possibility exists that part of this section may belong to the Hell Creek, based on a projection to the northeast of the thickness of sediments overlying the Pierre Formation and correlations from Morton, Oliver, and western Burleigh Counties. However, the areal distribution of the Hell Creek is not well known at the present time, and it may pinch out in eastern Burleigh County. Therefore, all of these rocks are herein referred to as the Fort Union (?) Group.

SELECTED REFERENCES

Caldwell, J. W., 1954, Summary of the Continental Oil Company—Nels Dronen No. 1 well: North Dakota Geological Survey Circular 39, 9 p.

Eisenhard, R. M., 1958, Summary of the Continental Oil Company, Pure Oil Company—J. F. Miller No. 1 well: North Dakota Geological Survey Circular 188, 10 p.

Hansen, D. E., 1959, Summary of the Magnolia Petroleum Company—North Dakota State "A" No. 1 well: North Dakota Geological Survey Circular 221, 11 p.

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

Nelson, L. B., 1954, Summary of Wilson Germany and Cardinal Drilling Company—W. H. Dickenson No. 1 well: North Dakota Geological Survey Circular 65, 3 p.

Smith, C. J., 1954 a, Summary of Wilson Germany and Cardinal Drilling Company— Gerhart Bahnmiller No. 1 well: North Dakota Geological Survey Circular 62, 4 p.

————, 1954 b, Summary of Wilson Germany and Cardinal Drilling Company—George Seibel No. 1 well: North Dakota Geological Survey Circular 64, 5 p.

Strassberg, M. D., 1953, Summary of the Carter Oil Company—North Dakota State No. 1 well: North Dakota Geological Survey Circular 32, 10 p.