NORTH DAKOTA GEOLOGICAL SURVEY

Wilson M. Laird, State Geologist

BULLETIN 51

NORTH DAKOTA STATE WATER COMMISSION

Milo W. Hoisveen, State Engineer

COUNTY GROUND WATER STUDIES 12

Geology and Ground Water Resources

of

WELLS COUNTY

Part 1–Geology

by

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and John R. Reid

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

1967

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

Contents

Page

Illustrations

(plates are in pocket)

Abstract

Wells County is in east-central North Dakota on the eastern flank of the Williston Basin. It is underlain by 4000 to 6000 feet of Paleozoic and Mesozoic rocks that dip gently to the west. The uppermost Cretaceous rocks, the Hell Creek, Fox Hills and Pierre Formations, lie directly beneath the glacial drift; isolated exposures of the Fox Hills and Pierre rocks occur in the Sheyenne River valley. Glacial drift covers the entire area averaging about 100 feet thick. In certain buried valleys it is more than 400 feet thick.

The northern two-thirds of Wells County lies within the Drift Prairie. This area is characterized by a surface of flat to gently rolling topography that is rugged on the end moraines and subdued on the ground moraine and outwash plains. Associated with these major landforms are numerous washboard moraines, meltwater trenches, and ice disintegration ridges. The southern third of Wells County is part of the Missouri Coteau, and is characterized by a hilly surface on dead-ice moraine. Associated with the dead-ice moraine are numerous kames, lake plains and areas of collapsed outwash topography. Surficial deposits throughout the county are chiefly till and outwash, but proglacial and postglacial lake sediments, colluvium, dune sand and recent alluvium are also present.

As the late Wisconsinan glacier in east-central North Dakota thinned and receded, a large portion of it on the Missouri Coteau stagnated and very slowly melted, resulting in hummocky areas of dead-ice moraine. The part of the glacier on the Drift Prairie that remained active was increasingly affected by topographic highs over which it flowed. This resulted in lobation of the ice and deposition of several end moraines from different directions. When a part of the glacier in north-central Wells County stagnated as a result of this lobation, it was dissected by streams that deposited numerous ice-contact ridges.

The most important economic resources in Wells County are the soil, ground and surface water, sand and gravel. Although no commercial oil production has yet been found, conditions necessary for stratigraphic traps exist and further exploratory drilling may prove successful.

Geology and Ground Water Resources of Wells County, North Dakota

by

John P. Bluemle, George A. Faigle, Ronald J. Kresl, and John R. Reid

INTRODUCTION

Purpose

This report is a descriptive and interpretive analysis of the geology of Wells County, an area of 1300 square miles in central North Dakota in Tps. 145-150 N., and Rs. 68-73 W. (fig. 1). It is one of a series of county reports conducted by the North Dakota Geological Survey in cooperation with the North Dakota State Water Commission and the United States Geological Survey. Reports on the ground water basic data and hydrology of the area will be published separately.

Primary objectives of this study were: 1) to provide an accurate map of the geology of Wells County; 2) to arrive at an understanding of the processes that shaped that geology; 3) to examine the relationship of the glacial geology to ground water conditions; and 4) to determine the location and extent of gravel and other resources of the area.

Methods of Study

During the 1963 field season, R. J. Kresl and G. A. Faigle, then graduate students at the University of North Dakota, mapped the geology of Wells County for their Master of Science degree theses. They traversed all section-line roads by automobile noting the composition of sediments in road cuts and hand-augered holes. Data were plotted on county road maps and United States Geological Survey maps of the 7 1/2 minute topographic series, scale 1:24,000. Aerial photograph stereopairs, scale 1:63,360, were available for the county. Numerous samples of till and fossiliferous sediments were collected by Faigle and Kresl for later laboratory analysis. Boulder, cobble and pebble composition analyses were made in the field. Colors of sediments were determined by comparison with the Rock Color Chart (Goddard and others, 1951).

During November of 1966, the senior author made a field check of Faigle's and Kresl's maps and made necessary corrections so the maps would conform to the standards of the North Dakota

Geological Survey. Some areas were completely remapped; in other areas only minor changes were needed.

Previous Work

The most comprehensive study now available on the Pleistocene geology of North Dakota is by Lemke and others (1965). Clayton (1966) has added to and revised this. Lemke and Colton (1958) summarized North Dakota Pleistocene geology and later published their *Preliminary Glacial Map of North Dakota* (Colton, Lemke and Lindvall, 1963). Other studies include those by Branch (1947), Easker (1949), and Tetrick (1949), of the glacial geology of three

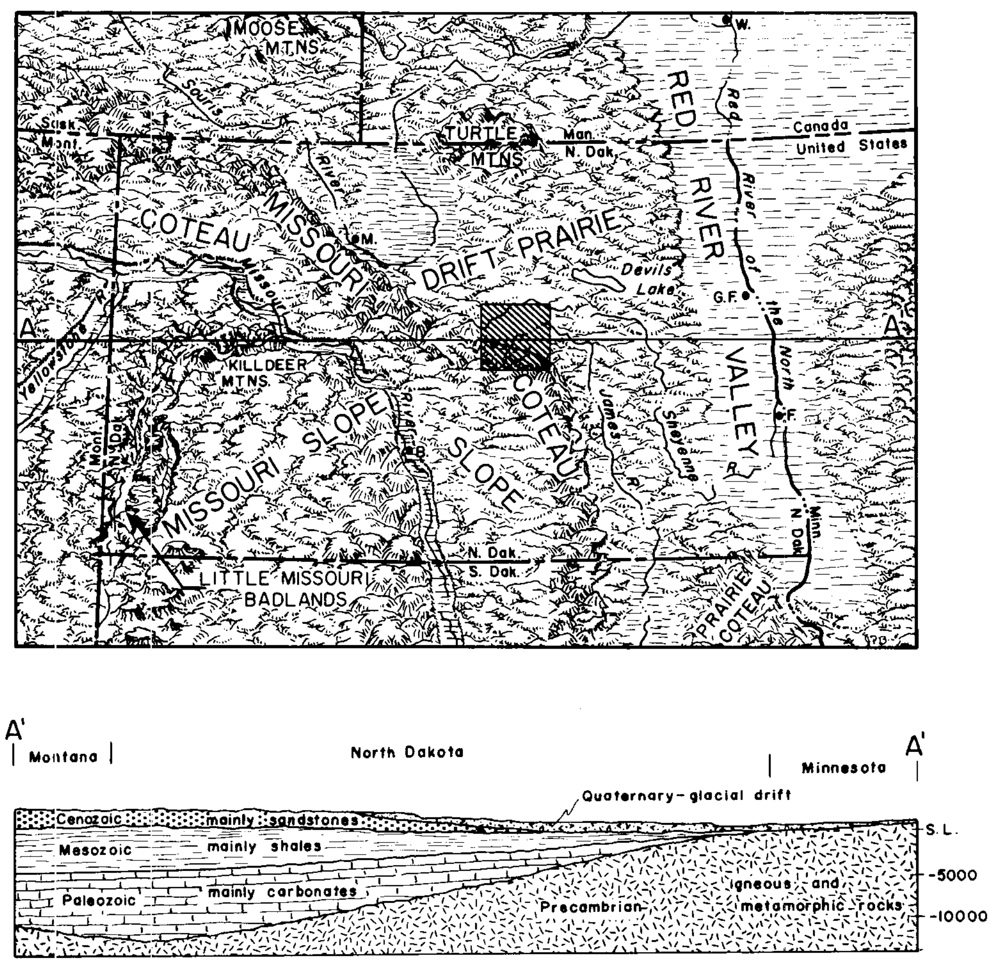

Figure 1. Index map. Shows the location of Wells County and the physiographic subdivisions of the surrounding area. The cross-section of the area is generalized to show regional relationships.

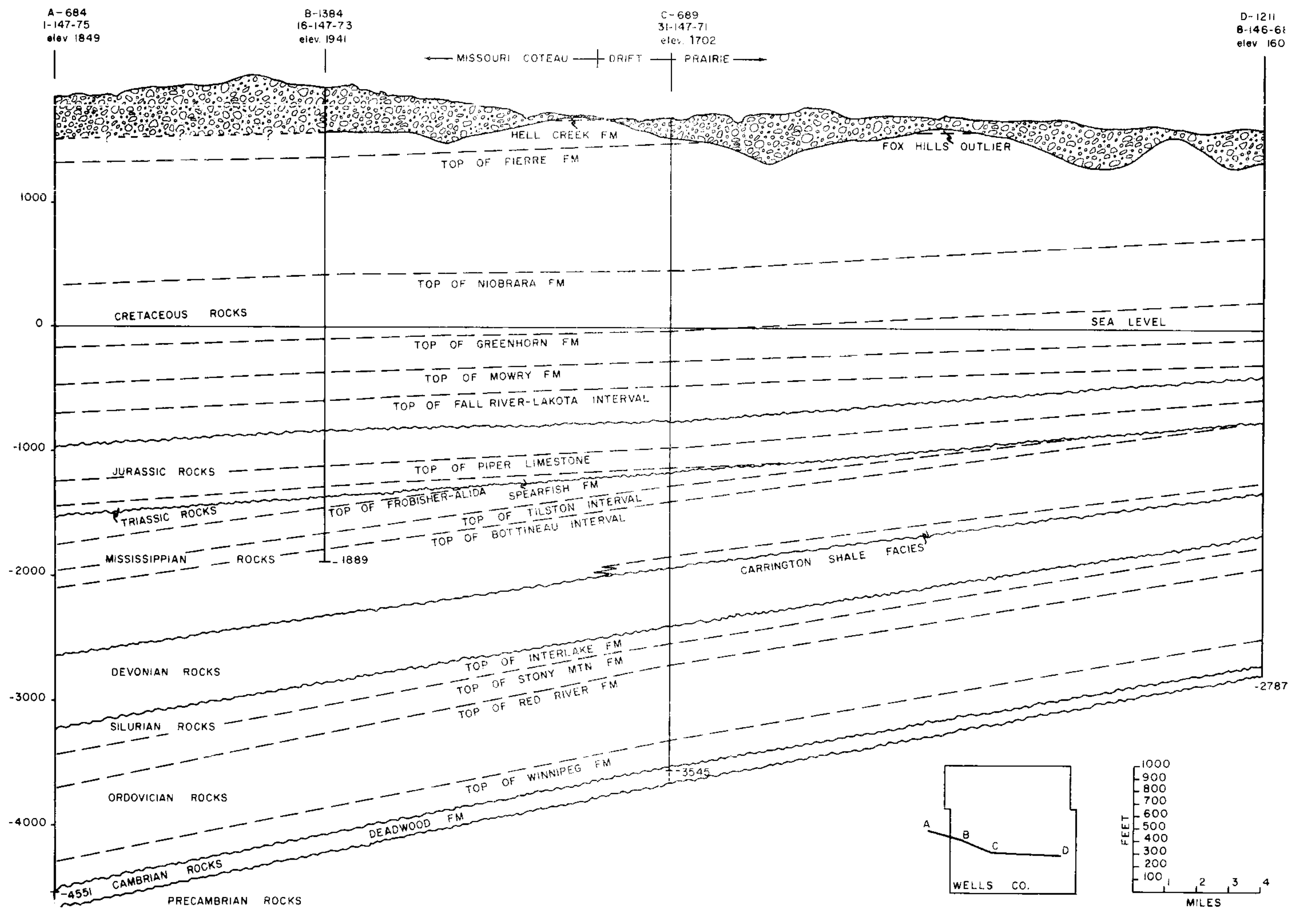

Figure 2. Diagrammatic cross-section of Wells County.

fifteen-minute quadrangles that include part of northern Wells County. Filaseta (1946) investigated the ground water of the Fessenden area. Several geologic reports of the present county series are now available for the area near Wells County; they include: Kidder County (Rau and others, 1962); Stutsman County (Winters, 1963); Burleigh County (Kume and Hansen, 1965); and Eddy and Foster Counties (Bluemle, 1965). A comprehensive study of the Paleozoic bedrock of eastern North Dakota (Ballard, 1963) includes the area covered in the present report. Several circulars describing samples from exploratory oil wells have been published and various general studies of North Dakota bedrock have included all or parts of Wells County.

Geography

Wells County has a short cool summer with a 117-day growing season and 17 inches of annual precipitation, most of which falls during the summer. This dry-subhumid climate is best suited for the production of small grains although some livestock is raised. Most of the county's population of 9231 is engaged in agriculture or agriculture-related industry. The largest town in the county is Harvey with a population of 2365. Fessenden, the county seat, has a population of 920.

PRE-PLEISTOCENE STRATIGRAPHY

General

Approximately 4100 to 6000 feet of Paleozoic and Mesozoic rocks lie on the Precambrian basement in Wells County (figs. 2 and 3). Beneath the glacial drift of Wells County three Cretaceous formations subcrop (pl. 2). These are the shale of the Pierre Formation which subcrops in the eastern part of the county and the Fox Hills and Hell Creek Formations which subcrop further west and southwest. Wells County is located near the eastern edge of the Williston Basin, so all the bedrock formations have a westerly regional dip and are thicker to the northwest. In this report only the bedrock that subcrops beneath the drift will be discussed.

Cretaceous Rocks

Pierre Formation—The Pierre shale crops out in northeastern Wells County along the walls of the Sheyenne River valley. Where weathered, the shale flakes and chips along distinct but discontinuous bedding planes. It is light gray and loose when dry, darker gray and cohesive due to included bentonite when wet. Some bentonitic zones have a popcorn-like surface when dry and contain yellow to buff streaks. Limonite stains are common on fractures and small iron concretions occur in abundance.

Fox Hills Formation—The Fox Hills Formation overlies the Pierre Formation shale in the central and western parts of Wells County. It outcrops in several places along the Sheyenne River near

Harvey and in a roadcut in the northwestern corner of the county. The Fox Hills Formation consists of greenish-gray to yellow, fine and medium-grained sandstones interbedded with gray siltstones. It weathers to a miniature badlands topography in the exposures south of Harvey; this is typical of the uppermost sandstone member of the Fox Hills.

Hell Creek Formation—The Hell Creek Formation overlies the Fox Hills Formation in southwestern Wells County where it was penetrated by at least one test hole. It is the youngest pre-Pleistocene formation in the county. The Hell Creek Formation is composed of a light gray, fine-grained siltstone that is moderately well cemented by a bentonitic clay. Dark mineral grains impart a "salt-and pepper" appearance to the siltstone.

PLEISTOCENE STRATIGRAPHY

Glacial History Prior to Deposition of the Surface Drift

Most of the information about the glacial history of Wells County before the surface drift was deposited was obtained from test hole logs. One phase of this history was the advance of the glacier that was responsible for the formation of the now buried Heimdal trench which contains the most important single aquifer in the county. As the ice advanced southward, it blocked the north-flowing drainage of the area diverting it to more southerly routes. The most important of the north-flowing drainages were the Knife and Cannonball rivers which flowed from southwestern North Dakota. Northeast of the Missouri River the valleys are buried by glacial drift. In the Wells County area, these two rivers joined with meltwater from the glacier forming proglacial lakes in the valleys (fig. 4). When the lakes overflowed the valley walls, a series of ice marginal trenches was cut; the most important of these in the Wells County area is the buried Heimdal trench. It formed along the ice margin in northern Wells County and eastward into Eddy, Foster and Griggs Counties (fig. 5).

After the ice advanced across this trench, it formed an outwash plain in T. 147 N., R. 68 W. of Wells County and eastward into northwestern Foster County (fig. 6). This outwash plain, now the buried Carrington aquifer, was bounded on the southwest by a bed-rock high that extended from northeast of Sykeston to southwest of Carrington. The northern and eastern boundaries of the outwash plain must have been the glacier margin.

Plate 2 is a map of the bedrock pattern beneath the drift. It shows the subcrop pattern of the Pierre, Fox Hills and Hell Creek Formations and the topographic configuration of the bedrock surface. Plate 3 shows several cross-sections drawn through the drift. Both of these plates are based on data secured from the North Dakota State Water Commission and the United States Geological Survey.

Glacial Phases and Associated Landforms

All the major landforms in Wells County are the result of glacial activity; they formed during the recession of the late Wisconsinan ice front from the area. South of North Dakota the glacier that had crossed the area consisted of two lobes, the James and Des Moines. By the time the ice margin had receded as far as central North Dakota, these lobes had probably lost their identities. Two succeeding lobes, the Leeds and Souris lobes developed from the receding

Systems	Rock Units	Thickness in feet (from top of named formation to top of next lower formation)	Dominant Lithology
Tertiary	Pleistocene	0-500	Glacial drift
Cretaceous	Hell Creek Formation	0-50	Siltstone
	Fox Hills Formation	0-250	Siltstone
	Pierre Formation	550-1100	Shale
	Niobrara Formation	450-500	Shale
	Greenhorn Formation	200-300	Shale
	Mowry-Newcastle Formations	200-250	Sandstone
	Fall River-Lakota Formations	100-200	Sandstone
Jurassic	Unnamed Interval	50-300	Shale
	Piper Formation	50-150	Limestone
Triassic	Spearfish Formation	0-80	Siltstone
Mississippian	Madison Formation		
	Poplar Interval	0-40	Dolomite
	Ratcliffe Interval	0-80	Limestone
	Frobisher-Alida Interval	0-210	Limestone
	Tilston Interval	30-150	Limestone
	Bottineau Interval	490-570	Limestone & shale
	Carrington Facies of the Bottineau	0-90	Shale
Devonian	Birdbear Formation	0-60	Limestone
	Duperow Formation	80-170	Dolomite
	Souris River Formation	170-250	Limestone
	Dawson Bay Formation	20-90	Dolomite
	Prairie Formation	10-50	Dolomite
	Winnipegosis Formation	0-80	Shale
Silurian	Interlake Formation	20-220	Dolomite
	Stonewall Formation	60-80	Dolomite
	Stony Mountain Formation	130-150	Dolomite
	Red River Formation	580-620	Limestone
	Winnipeg Formation	190-210	Shale
Cambrian	Deadwood Formation	30-210	Sandstone & Dolomite
Precambrian			Igneous and metamorphic rocks

Figure 3. Stratigraphic column of Wells County.

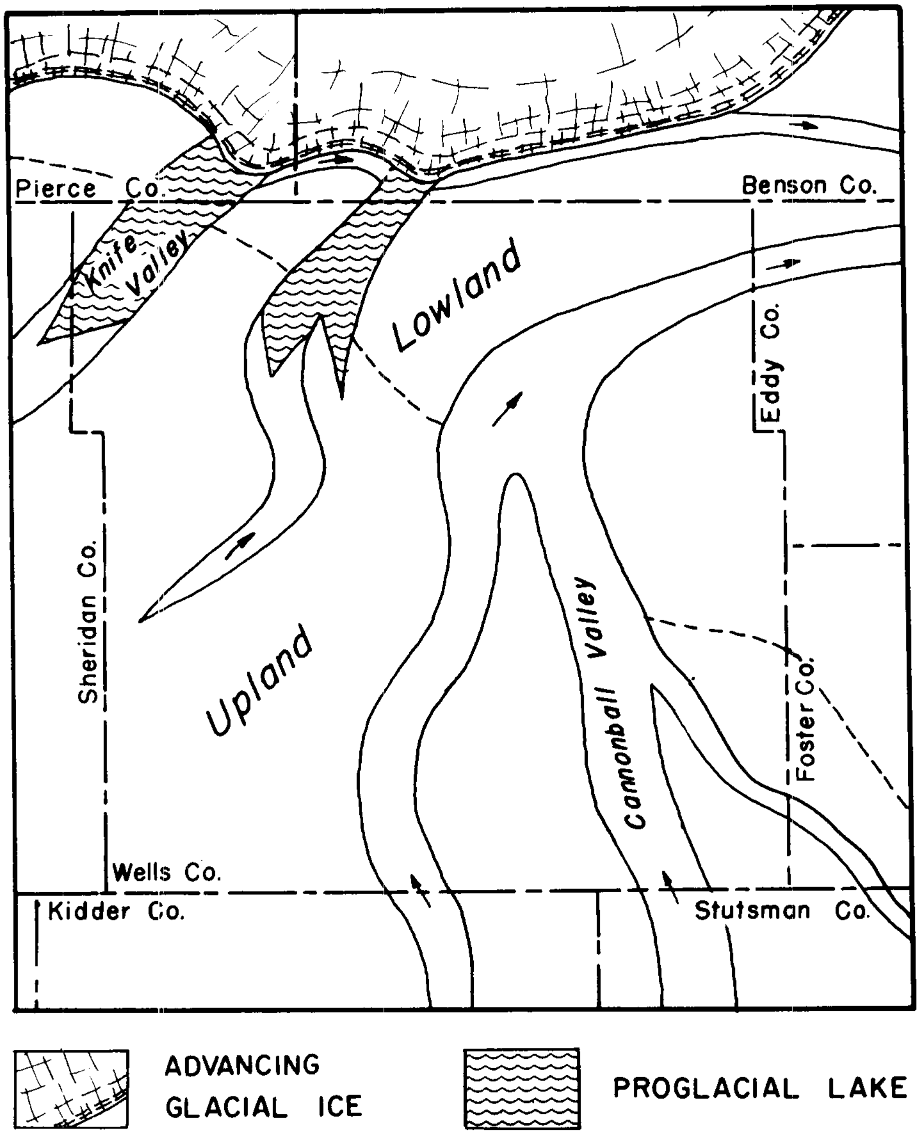

Figure 4. Advance of the Wisconsinan ice. Proglacial lakes have formed in the Knife valley and its tributary valley. Water flowing through the Cannonball River system is unaffected at this time.

James lobe when the Turtle Mountains on the North Dakota Canadian border changed the flow direction of the ice which had become too thin to override them.

It is possible to construct a sequential history of ice recession over Wells County and adjacent areas. For purposes of discussion, it is convenient to single out ice phases that occurred while the glacier margin was receding through Wells County. Figure 7 shows the areas affected by each of these phases.

In general, each of the glacial phases discussed here is characterized by an end moraine with associated ground moraine and outwash plains. The most important exception to this generalization

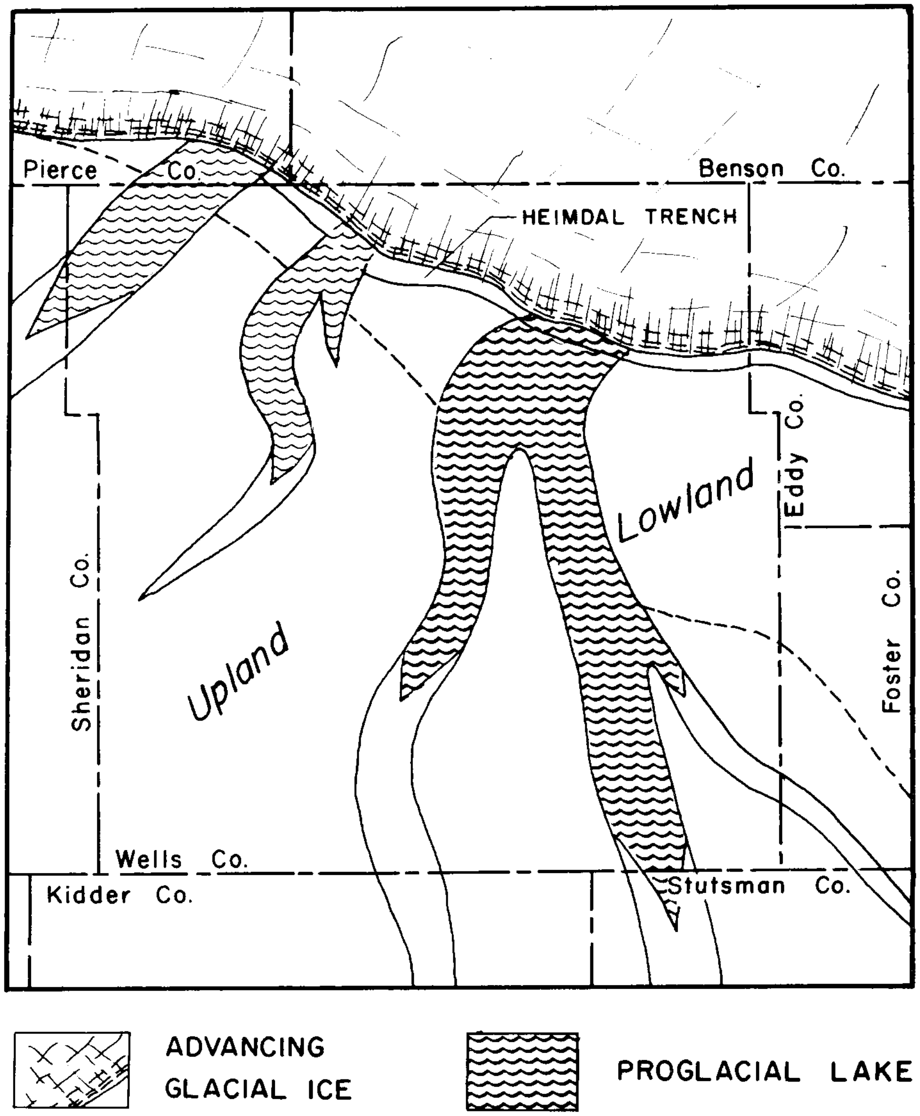

Figure 5. Cutting of the Heimdal trench. Meltwater and water of the Knife and Cannonball drainage systems have overflowed the preglacial valleys, cutting an ice-marginal trench through northern Wells and Eddy Counties.

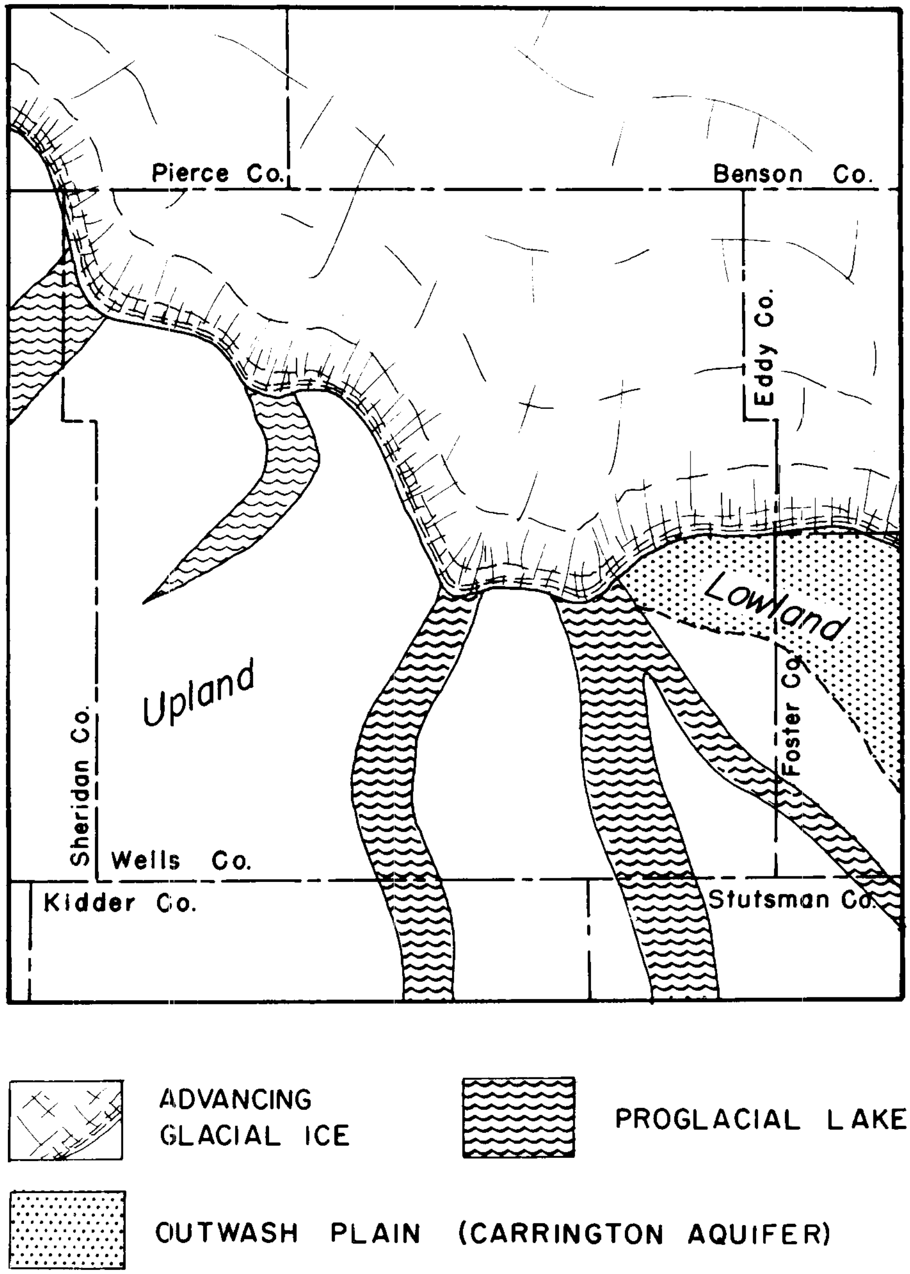

Figure 6. Deposition of the Carrington aquifer. The ice here has advanced over the Heimdal trench and the dammed meltwater is flowing eastward between the ice and the bedrock upland on the south, depositing outwash that was later to be covered by till. This outwash is now the buried Carrington aquifer, the shaded area above.

is the Streeter phase which resulted in wide areas of glacial stagnation on the Missouri Coteau. Developed on the major landforms are smaller features such as eskers, kames, disintegration ridges and washboard moraines.

Streeter Phase

History—During the Streeter phase, the edge of the active ice that covered nearly all of Wells County was along the Wells-Kidder county line (fig. 8). The Streeter end moraine marks the edge of the active ice that was responsible for the enormous amounts of outwash sand and gravel in central Kidder County. Although glacial ice still existed west of the active Streeter ice front, it had already stagnated and was covered by a layer of debris that served to insulate the underlying ice and prevent rapid melting. For a more thorough discussion of the origin of dead-ice moraine, see Clayton (1962, p. 34-38).

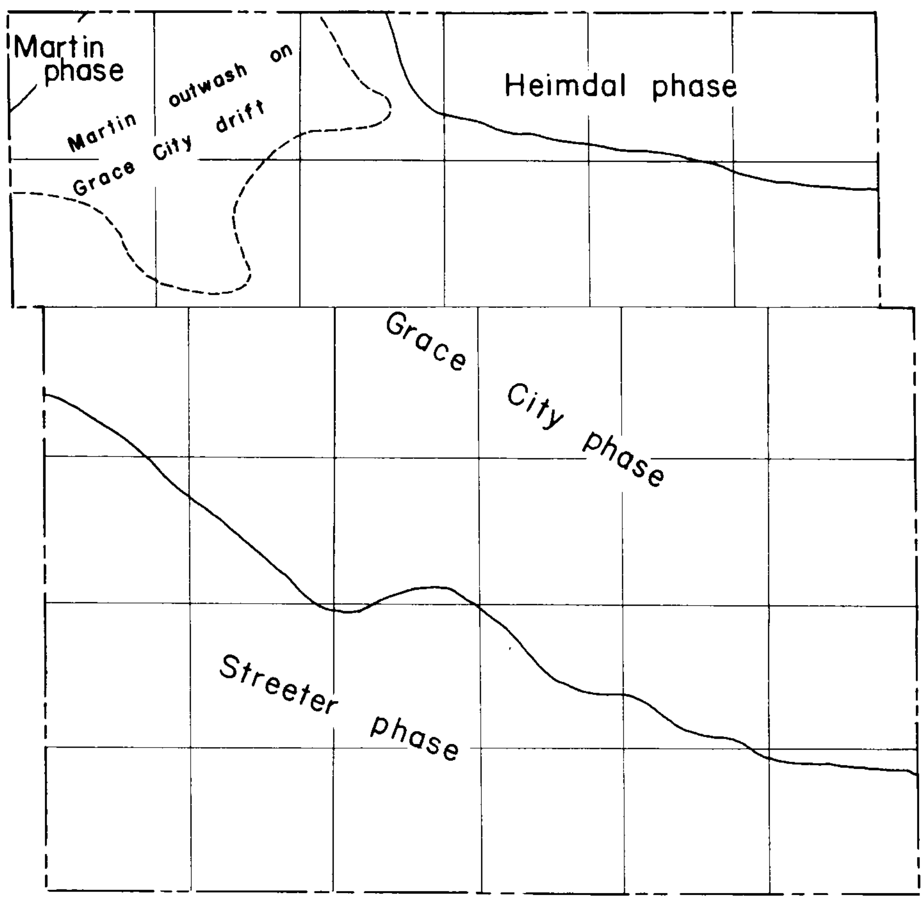

Figure 7. Map of Wells County showing the areas directly affected by each glacial phase.

Streeter drift—Drift of the Streeter phase covers about 30 per cent of Wells County, almost entirely in the southern part (fig. 7).

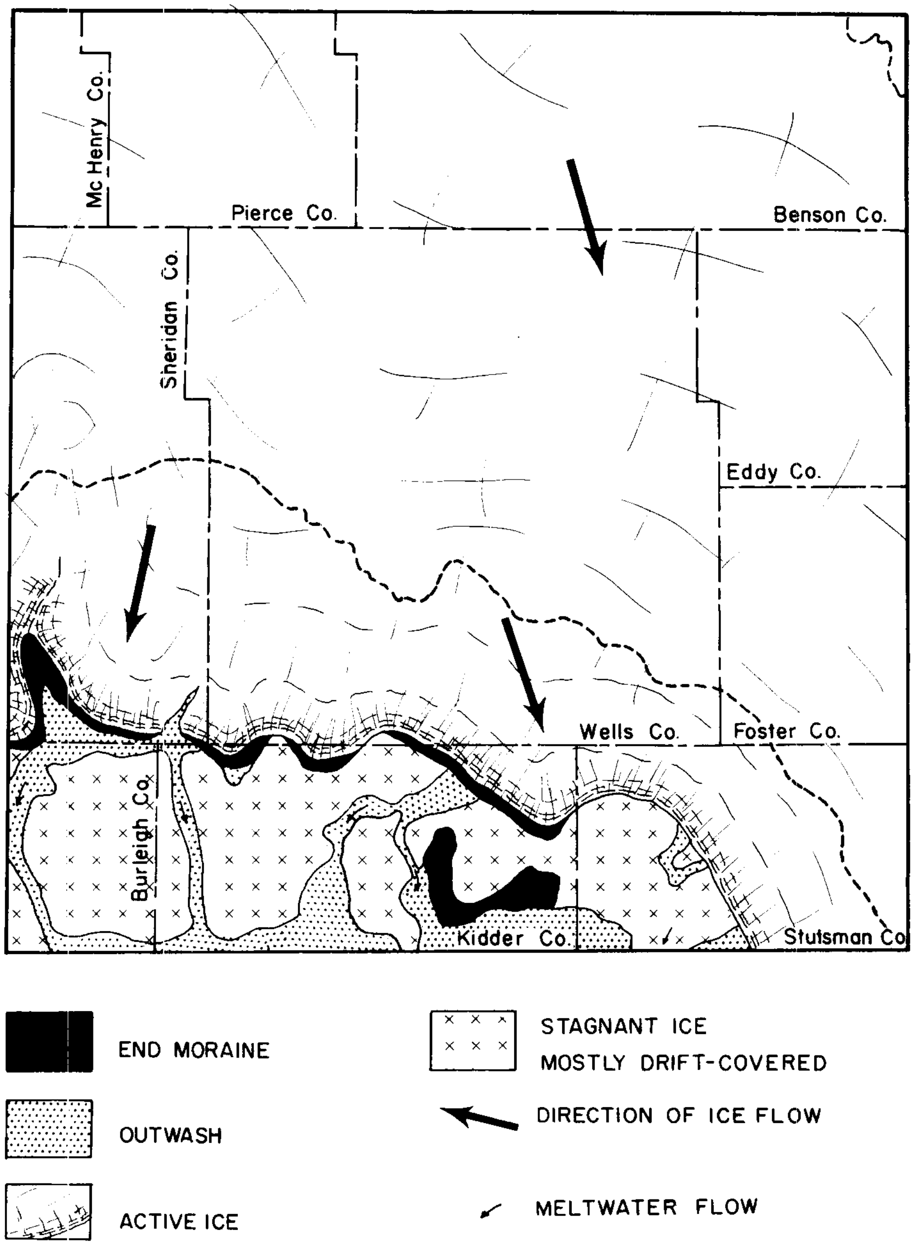

Figure 8. Formation of the Streeter end moraine. Water flowing from the melting ice deposited broad areas of outwash sand and gravel in Kidder County to the south.

The drift consists of till of the Streeter end moraine and the dead-ice moraine north of it, as well as associated gravel of collapsed outwash and ice-contact ridges. It also includes deposits of lake sediments within the dead-ice moraine. The Streeter drift was named by Lemke and Colton (1958, p. 49) for the town of Streeter in southwest Stutsman County.

The Streeter drift is the oldest surface drift in Wells County. It was deposited from ice that stagnated on the Missouri Coteau. The Streeter end moraine probably marks the last important active margin of the ice that flowed over the Missouri Coteau. It probably represents only a slight readvance of the Burnstad ice sheet and the upper Burnstad drift is probably only slightly older than the Streeter drift.

Radiocarbon dates from Streeter and Burnstad drifts in Logan, McIntosh, Stutsman and Kidder Counties range from 9000 to 11,650 years before the present (Clayton, 1962, p. 68). Clayton concludes that the lower Streeter drift was deposited 11,650 ± 310 years ago and the upper Burnstad drift was deposited continuously from slowly melting, stagnant glacial ice between 12,500 and 9,000 years ago. This interval indicates that the stagnant glacial ice took about 3500 years to melt (Clayton, 1962, p. 68).

Fossil freshwater gastropod and pelecypod shells, ostracode carapaces and charophytes occur in several collapsed and elevated lake deposits within the Streeter drift. They are as follows:

1. A lake clay beneath a collapsed lake deposit in the SE¼, sec. 6, T. 144 N., R. 68 W.

2. A lake clay beneath a collapsed lake deposit in the SW¼, sec. 35, T. 145 N., R. 69 W.

3. A lake clay beneath an elevated lake plain 0.1 mile east of the NW¼, sec. 25, T. 145 N., R. 71 W.

4. A lake clay beneath a collapsed lake deposit along the east side of sec. 13, T. 145 N., R. 71 W.

5. A lake clay beneath an elevated lake plain in the NW¼, sec. 14, T. 145 N., R. 70 W.

6. A lake clay beneath a collapsed lake deposit on the east side of sec. 17, T. 145 N., R. 69 W.

7. Lake sediments beneath a collapsed lake deposit in the NE¼, sec. 35, T. 146 N., R. 71 W.

8. Lake sediments beneath a collapsed lake deposit on the east side of sec. 10, T. 146 N., R. 71 W.

9. A lake clay beneath a collapsed lake deposit in the NW¼, sec. 12, T. 146 N., R. 71 W.

10. A very fine sand with interbedded lake clays beneath

an elevated, collapsed lake deposit in the SW¼, sec. 6, T. 146 N., R. 70 W.

11. A lake clay beneath an elevated lake plain in the NE¼, sec. 29, T. 146 N., R. 70 W.

12. Lake sediments beneath a collapsed lake deposit in the NE¼, sec. 32, T. 147 N., R. 73 W.

13. Lake sediments beneath a collapsed lake deposit on the north side of sec. 17, T. 147 N., R. 73 W.

A composite list of the fossils identified from these deposits of ice-contact washed drift is as follows; the numbers represent the sites each fossil was found at:

Fresh-water snails

Armiger crista (Linnaeus)	— 2, 4, 7, 9, 12 13
Gyraulus parvus (Say)	— all sites except 3, 6, and 11
Gyraulus sp.	— all sites except 2, 9, 12, and 13
Helisoma anceps (Menke)	— 1, 4
Lymnaea humilis (Say)	— 5, 7, 8, 9, 12, 13
Lymnaea sp.	— 2, 12
Physa sp.	— 7, 9
Promenetus exacuous (Say)	— 12
Succinea sp.	— 15
Valvata lewisi Currier	— 4, 6, 10
Valvata tricarinata (Say)	— all except 9 and 11

Sphaerid clams

Sphaerium sp.	— 10
Pisidium sp.	— 2, 4, 5, 7, 8, 9, 12

Ostracodes

Candona candida (Muller)	— 11
Candona nyensis Gutentag and Benson	— 11
Candona parachioenais Staplin	— 5
Candona renoensis Gutentag and Benson	— 2
Candona sp. aff. C. *subtriangularis* Swain	— 2, 5, 11
Cyclocypris forbesi Sharpe	— 3, 5, 11
Cypridopsis vidua (Muller)	— 2, 5
Cytherissa lacustris Sars	— 2, 3, 11
Ilyocypris gibba (Ramdohr)	— 5, 11
Limnocythere friabilis Benson and McDonald	— 3, 5, 11
Limnocythere sp.	— 6

Stoneworts

Chara spp.	— 2, 5, 10, 11

The mollusk identifications are from Kresl (1964, p. 73-75) and

Faigle (1964, p. 71-74). Dr. R. Green, Head of the Geology Division, Research Council of Alberta, identified the ostracodes.

The oogonia and calcified stem fragments of the genus *Chara* are found at some of the fossil sites. *Chara* is a small bushy plant that grows in clear waters of lakes and ponds; it may also be found in near-shore waters where there is a high influx of fresh water (Jones, 1956, p. 37). Abundant vegetation was probably present near the shores of many of the lakes.

Most of the area associated with the Streeter phase is dead-ice moraine. Other landforms include end moraine, disintegration ridges, collapsed and elevated lake deposits, collapsed outwash plains, kames, and meltwater trenches. Drainage is in the youthful stage and post-glacial erosion has been negligible except where headward erosion of gullies is now beginning to dissect the northeast slope of the Coteau.

GLACIAL LANDFORMS

End moraine—End moraine is defined as a ridge of drift, chiefly till, with moderate to high local constructional relief and either overall or internal linearity, or both. It is the result of glacial deposition at the margin of an active glacier. Linearity, the primary requisite for recognition of an end moraine may be revealed by the presence of small lineations, such as hills, ridges or depressions or it may be revealed solely by the overall pattern.

The Streeter end moraine consists of three segments that extend from section 31 to 36 of T. 145 N., R. 73 W.; from section 24, T. 145 N., R. 73 W. to section 32, T. 145 N., R. 72 W.; and from section 30 to 35 of T. 145 N., R. 71 W. Rau (1962, p. 29) named the westernmost of these segments the West Woodhouse Lake Loop. and the easternmost segment the East Woodhouse Lake Loop. The central segment he called a bedrock high, but, although it does lie on the flank of a bedrock high, it apparently is not cored by bedrock and should therefore be considered to be another loop. In this report it will be referred to as the Middle Woodhouse Lake Loop.

All three segments of the Streeter end moraine of Wells County lie on the southern border of the county and continue into Sheridan and Kidder Counties. The boundary of the West and Middle Woodhouse Lake Loops is gradational with dead-ice moraine; there is no distinct change in relief. The outer edge of the West Woodhouse Lake Loop is about a mile south of Wells County in Kidder County. Here, the contact is prominent and lineations are evident on aerial photographs. The end moraines are composed of a calcareous, stony, clay till that is yellowish-gray (5Y-7/2) when dry and moderate olive-brown (5Y 4/4) when wet. Numerous boulders are concentrated on the surface.

The East Woodhouse Lake Loop extends about three miles into Wells County from Kidder County. It is about one mile wide. The end moraine decreases from a prominent feature with 150 to 200 feet of relief to an indistinct feature on the northwest where it merges with dead-ice moraine. The composition of the end moraine is similar to that of the West and Middle Woodhouse Lake Loops.

Dead-ice moraine—Dead-ice moraine results from the slow ablation of a large mass of stagnant ice which is veneered with glacial sediments. Shearing within the ice as it moves over an obstruction such as the Missouri Coteau brings subglacial till up into the glacier where subsequent ablation concentrates it on the surface. Running water and mass wasting redistribute the surface debris into such features as outwash plains, lakes, and randomly-oriented mounds of till all resting on stagnant ice. Complete melting of the stagnant ice results in the collapse of the previously-formed features and the undulating topography of dead-ice moraine results. For a discussion of dead-ice moraine terminology and a summary of the modes of origin see Clayton (1962, p. 34-38).

Most of the Missouri Coteau in Wells County is characterized by dead-ice moraine (fig. 9). Relief on the dead-ice moraine averages less than 40 feet in a mile, but in places it is greater than 150 feet in a mile. Drainage on the dead-ice moraine is non-integrated and the surface consists of innumerable depressions with randomly distributed hummocks. In areas of relatively low relief, immature drainage systems have begun to develop and some of this land is under cultivation.

The most prominent feature on the Missouri Coteau of Wells County is Hawks Nest, a topographic and bedrock high, 6 square miles in area, in the extreme southeast corner of the county. Hawks Nest projects 300 to 400 feet above the surrounding terrain and it is characterized by high-relief hummocks and circular disintegration

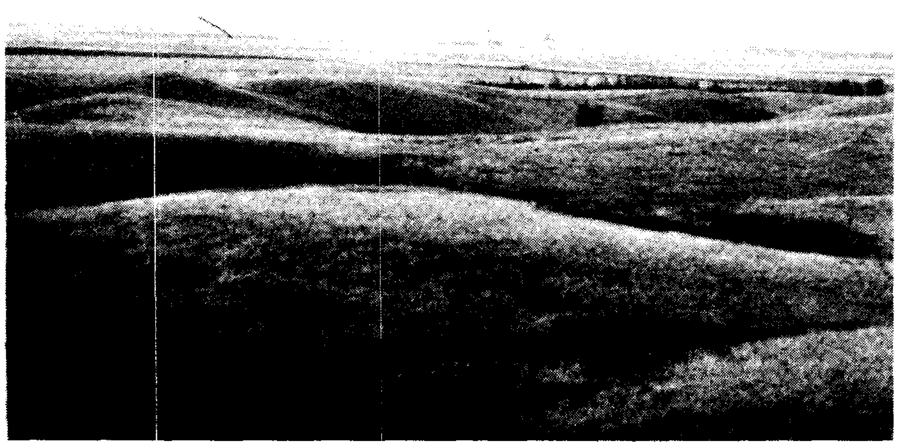

Figure 9. Photograph of dead-ice moraine. Section 2, T. 147 N., R. 73 W. Photo by George Faigle.

Figure 10. Photograph of ice-thrust deformation of glacial drift. Exposed in a road cut in the SW¼, sec. 21, T. 145 N., R. 71 W. Photo by George Faigle.

ridges. It is overlain in places by sand and gravel deposits as much as 40 feet thick.

Generally, the till of the dead-ice moraine is calcareous, stony and clayey, yellowish-gray (5Y 7/2) when dry and moderate olive-brown (5Y 4/4) when wet. Boulders are few too scarce on the dead-ice moraine.

Linear disintegration ridges—Disintegration ridges are linear to circular accumulations of drift deposited in direct association with masses of stagnant ice. The sediments were deposited largely by mass movement of superglacial drift into cracks in stagnant ice or between isolated blocks of ice, or by unfrozen, saturated sediments being squeezed up into the cracks or around the blocks by the weight of the ice. Linear disintegration ridges are straight to rectilinear ridges of till and/or outwash sediments.

Several well-developed disintegration ridges occur in the area that was covered by the Streeter ice. An excellent example is the one in section 21, T. 147 N., R. 72 W. This ridge is 4000 feet long, 600 feet wide and 70 feet high and it is composed, at least in part, of poorly-stratified sand and gravel. A dense concentration of boulders exists on the surface. The feature has a 90 degree bend in the middle.

Two longer but less prominent disintegration ridges are found in sections 26, 35 and 36, T. 147 N., R. 73 W. and sections 5 and 6, T. 146 N., R. 73 W. These features also have rectilinear shapes.

Circular disintegration ridges—Circular disintegration ridges are a characteristic landform of the lower relief dead-ice moraine in Wells County. These ridges are 300 to 500 feet in diameter, less than five feet high and they are composed of till. They can be observed on aerial photographs as rimmed depressions but they can seldom be detected on the ground. Circular disintegration ridges probably formed either by squeezing up of till around isolated blocks of stagnant ice or by reversal of relief of sediments deposited in a depression in the stagnant ice.

Collapsed lake topography—Collapsed lake topography results when the sediments deposited in a superglacial lake are irregularly lowered as the stagnant ice melts. Collapsed lake topography has a rolling appearance and a boulder-free surface. An area of collapsed lake topography of about 4 square miles occurs in sections 26-28 and 33-35, T. 145 N., R. 70 W. Its surface is flat to gently undulating and underlain by about 5 feet of very cohesive, non-fossiliferous clay. Isolated patches of till are common on the surface. A 3½ square-mile area of partially collapsed lake sediments occurs in sections 1, 2, 10, 11, and 12, T. 146 N., R. 71 W. and sections 6 and 7, T. 146 N., R. 70 W. Relief there averages less than 20 feet in a square mile. Fossiliferous clays, silts, marls, and fine sands occur beneath the surface.

Elevated lake plains—Elevated lake plains result from initial deposition of sediments in ice-walled lakes. When the ice melts and the lake drains, the lake bottom that has been covered by lake sediments becomes a topographic high. The surfaces of the elevated lake plains in Wells County are level or gently undulating. They extend 5 to 15 feet above the surrounding dead-ice moraine and they lack surface pebbles and cobbles. Most of the Wells County elevated lake plains contain abundant Pleistocene fossils. The largest elevated lake plain in Wells County is about 3 square miles in area in sections 31, 32 and 33, T. 145 N., R. 69 W. (pl. 1). Many of the lake plains are too small to include on the map of the county.

Collapsed outwash—Collapsed outwash results when sand and gravel is deposited by meltwater on stagnant ice. When the ice melts, the outwash is irregularly lowered forming abundant kettles and trenches and a generally very uneven surface. Collapsed outwash occurs in sections 6, 7, 17, 18, 19 and 30, T. 145 N., R. 73 W.

Kames—Clayton (1962, p. 40) restricts kames in areas of dead-ice moraine to conspicuous hills of sand and gravel that are more prominent than the surrounding hills. Kames fitting Clayton's definition are found in the NE¼, sec. 7, T. 145 N., R. 72 W.; NW¼ sec. 22, T. 145 N., R. 73 W., and the SW¼, sec. 31, T. 146 N., R. 72 W. At this last location, the internal structure of the kame is exposed in a sand and gravel excavation. All the layers dip away from a central high point.

PROGLACIAL LANDFORMS

Proglacial landforms such as outwash, meltwater trenches, and lake sediments are scarce and do not significantly affect the topography of the Missouri Coteau in Wells County. Several small meltwater trenches trend northward off the Coteau escarpment, however. One heads in section 11, T. 145 N., R. 70 W., one in section 26, T. 145 N., R. 68 W. and another enters the county in section 32, T. 145 N., R. 68 W. and trends northward. These meltwater trenches probably drained the buried stagnant ice on the Coteau after the active ice margin had retreated to somewhere north of the escarpment. Extensive deposits of outwash, although absent in this part of Wells County, occur south of the Streeter end moraine in Kidder, Logan and Sheridan Counties.

POSTGLACIAL LANDFORMS

Lakes and sloughs are very numerous and their abundance is typical of dead-ice moraine areas. The lakes and sloughs occupy low spots in the irregular topography. Those lakes and sloughs floored by impermeable clay till contain saline water, the level of which fluctuates with changes in the rates of evaporation and precipitation. Other lakes and sloughs underlain by stratified sand and gravel, contain fresh water and have a more stable level. These represent the intersection of a depression with the true water table.

Grace City Phase

History—Withdrawal of the active ice front from the position it had occupied when it deposited the Streeter end moraine resulted in stagnation of much of the ice on the Coteau in Wells County (fig. 11). Some active ice remained on lower parts of the Coteau, but if this ice deposited any end moraines they later collapsed when the underlying stagnant ice melted. Lineations (pl. 1) mark the ice borders shown on the Coteau in figure 11. During this part of the Grace City phase, the Grace City end moraine was deposited in Foster and Stutsman Counties.

On figure 12, the margin of the ice is shown shortly after it had deposited the Grace City end moraine. Although some active ice is still shown on the Coteau, most of it by this time was limited to the areas north of the Coteau. The lobe of active ice still on the Coteau supplied meltwater to several lakes in the dead-ice moraine. These lakes drained through a now collapsed meltwater channel at the margin of the small ice lobe. Meltwater from the active ice north of the Coteau became dammed in places and overflowed scutheastward between the edge of the ice and the front of the Coteau resulting in kame terraces and deep meltwater channels along the edge of the Coteau.

On figure 13, the active ice is shown at a still later stage. At about this time the Pony Gulch end moraine was deposited. Elsewhere in the county, meltwater from the receding glacier flowed through an intricate network of channels to the southeast. In central Wells County, much of the meltwater flowed along the margin of the ice and many of the channels mark the former positions of the ice as it receded from that area.

Grace City drift—Drift of the Grace City phase covers about 45 per cent of Wells County. Its southern boundary coincides with the Missouri Coteau escarpment and its northern boundary with the southern limit of the Heimdal-Martin drift. The drift consists of till of the ground moraine that extends through central Wells County as well as associated gravel of the outwash plains south of Fessenden and the many ice-contact ridges. The name "Grace City" was first applied to the Grace City end moraine by Lemke and Colton (1958, fig. 5) and the Grace City drift was defined in Eddy and Foster Counties (Bluemle, 1965, p. 24) as the drift associated with the Grace City end moraine which is named for the town of Grace City in north-central Foster County.

The Grace City drift was deposited after active ice was no longer present on the Coteau. It resulted from an ice flow from the northwest, probably the Souris River ice lobe, that came into existence as a result of thinning of the ice in the vicinity of the Turtle Mountains (Lemke, 1958, p. 51). It should be pointed out that the actual forward flow of the ice was continuous; no re-advance is implied, only a change in flow-direction. The Grace City ground moraine is truncated in northern Wells and Eddy Counties by the Heimdal end moraine which was deposited from the north by ice flowing around the west side of Sully's Hill.

Only one radiocarbon date (W-1369) has been taken from the Grace City drift but, because sampling procedures were inadequate, this date should be disregarded. Several years elapsed from the time the wood was discovered until it was dated and all information concerning its discovery is hearsay.

Most of the area associated with the Grace City phase is ground moraine. Four small end moraines, three of which were apparently overridden by the Grace City ice, are present in the area. Other landforms include eskers, kames, lake plains, washboard moraines, meltwater channels, outwash plains and terraces along the Sheyenne River.

GLACIAL LANDFORMS

Overridden end moraines—An 8-mile-long segment of overridden end moraine occurs from about 2 miles northwest of Sykeston to 6 miles southeast. Although its arcuate shape implies deposition from the northeast, surface lineations indicate that southeast-flowing ice may have overridden it. Another possibility is that the feature first developed along the edge of the receding Grace City glacier. The end moraine is separated from the dead-ice moraine of the Missouri Coteau by a meltwater trench; elsewhere it merges with Grace City ground moraine. Local relief averages between 20 and 40 feet

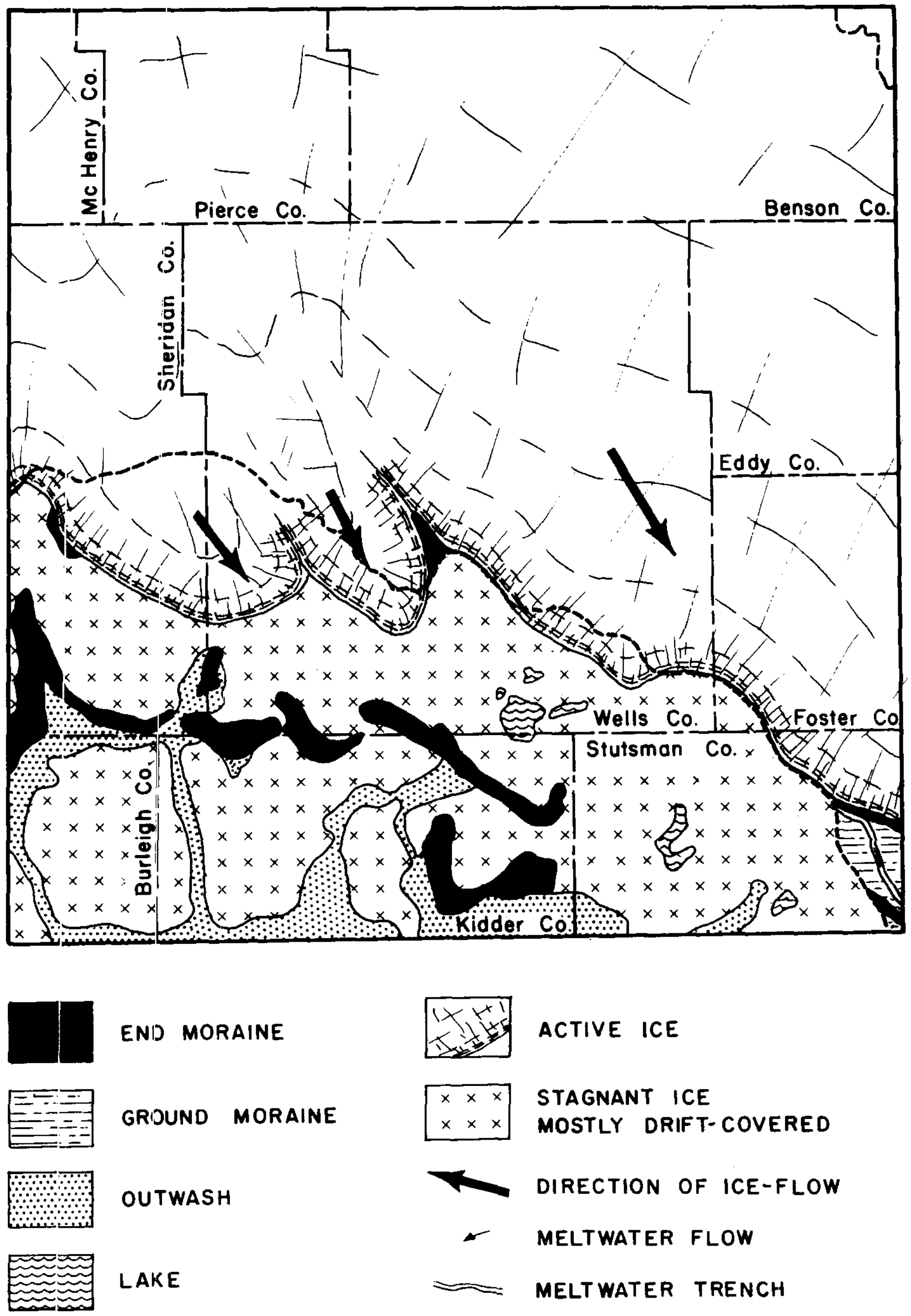

Figure 11. Early Grace City phase. During this phase the Grace City end moraine was formed in Stutsman and Foster Counties. In Wells County some active ice still remained on the Coteau.

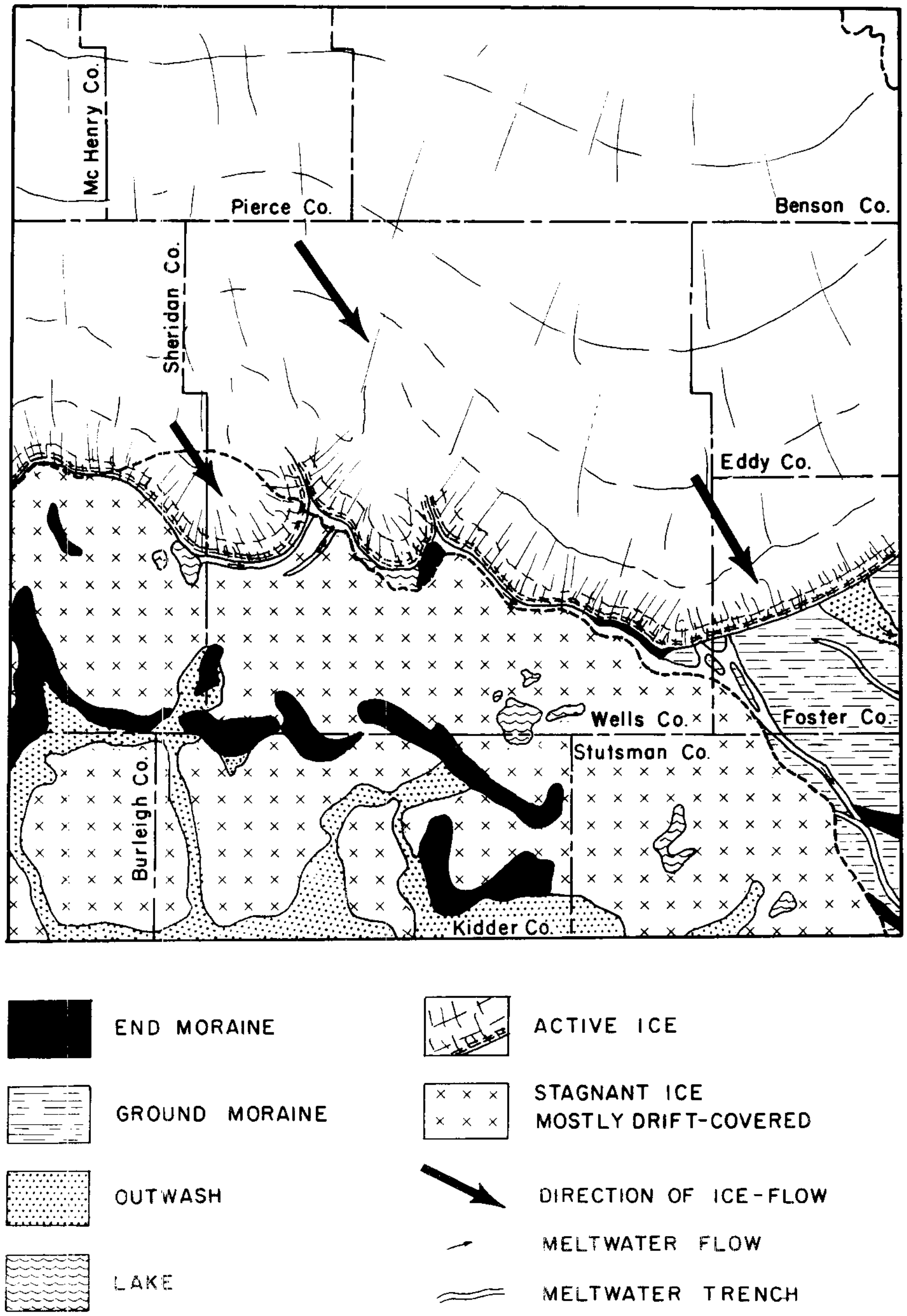

Figure 12. Intermediate Grace City phase. During this phase small end moraines were deposited at the edge of the Coteau and meltwater that flowed between the ice-front and the edge of the Coteau cut deep trenches.

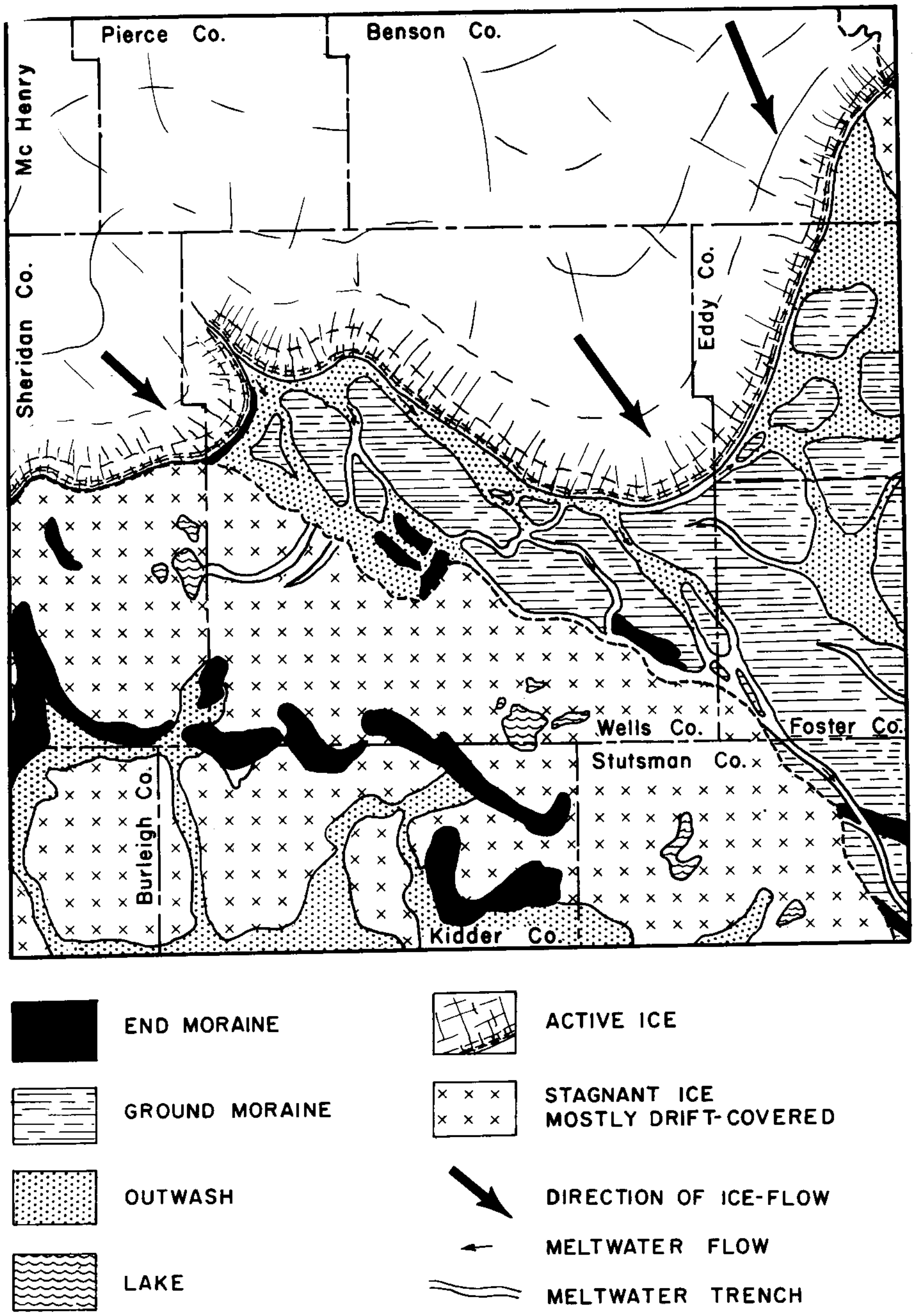

Figure 13. Pony Gulch phase. When the ice margin was in the position shown here, the Pony Gulch end moraine formed. Meltwater flowed from the ice depositing thin, but extensive deposits of sand and gravel in the areas shown.

in a mile, considerably more than on the ground moraine to the northeast, but less than on the nearby dead-ice moraine. The till on the surface of the overridden end moraine is sandy, much like that of the adjacent ground moraine.

Another small overridden end moraine is located between 8 and 11 miles southwest of Fessenden in T. 147 N., R. 71 W. (pl. 1). Again, the overall shape suggests deposition from the northeast and the streamlined surface indicates the end moraine has been overridden by southeast-flowing Grace City or older ice but it is likely the end moraine first formed at the margin of the Grace City ice (fig. 12). Local relief is low but the ridges rise more than 60 feet above the surrounding ground moraine and merge with dead-ice moraine on the southeast. The till on the overridden end moraine seems to be siltier than typical Grace City till.

About 5 miles northeast of Harvey in northern Wells County and extending into Pierce County is a third end moraine that appears to have been overridden by south-flowing ice. This small loop of overridden end moraine is as much as 150 feet higher than the surrounding terrain; its most conspicuous prominence is the Butte De Morale in sections 2, 3, 10 and 11, T. 150 N., R.72 W. Several individual hills of the end moraine show strong northwest-southeast linearity but the overall loop-like shape of the feature indicates it must have been deposited by a small south-flowing ice lobe. Another possible interpretation of this feature is that it represents a till-veneered bedrock high. The till of this feature is indistinguishable from that of the nearby ground moraine except for the fact that windblown deposits from adjacent outwash make the surface more sandy.

A 0.5 to 0.8 mile wide, 50- to 70-foot-high ridge extends from section 25, T. 149 N., R. 73 W. to section 20, T. 148 N., R. 73 W. Outwash deposits of sand and gravel exist on the down-glacier side of the ridge (pl. 1) so it seems likely the ridge is a segment of end moraine deposited by the receding Grace City ice sheet. Washboard moraines behind the ridge and parallel to it tend to confirm this conclusion. The ridge is composed of clayey till and the surface is covered by numerous boulders.

Ground moraine—Ground moraine is a gently undulating accumulation of drift, chiefly till, with low local constructional relief, generally less than 50 feet in a square mile. Material in ground moraine includes drift that has been directly influenced by the base of the moving glacier (lodgement till) and drift that has been lowered from upon and within the melting ice (ablation till).

The ground moraine associated with the Grace City phase is characterized by smooth topography, gentle slopes and relief averaging between 5 and 20 feet in a square mile. Poorly-drained depressions occur but they are not as numerous as in the dead-ice moraine of the Streeter phase. The highest elevations are at the base of the Missouri Coteau near Heaton at about 1750 feet and 4 miles southeast of Harvey at about 1700 feet. The lowest elevations of about 1550 feet are at the eastern edge of the county.

Abundant washboard moraines occur on the Grace City ground moraine. These are arcuate ridges of till, some of which are formed by the shearing action of active ice over relatively inactive ice. Subglacial debris is brought to the surface of the ice and deposited as ice-cored ridges (Bishop, 1957). Some of the washboard moraines may be formed simply as recessional features at the margin of the ice and may thus be annual deposits. Washboard moraines are particularly abundant in the Fessenden and Manfred areas (pl. 1). Their average width is about 20 feet, their height 5 to 15 feet and their length up to 4000 feet. They are spaced at distances up to 2700 feet apart but 600 feet is the average distance between them. They are difficult to recognize without aerial photographs. Because washboard moraines commonly form normal to the direction of ice flow, they are useful in determining the direction and possibly the rate of retreat of the ice lobe that formed these features (Gwynne, 1942, p. 200). Gravenor and Kupsch (1959, p. 55) regard the preservation of the washboard moraines as the result of stagnation of the glacier ice. This is substantiated by ice disintegration features that are superimposed on the ridges in Wells County. Numerous eskers that probably formed in a stagnant or nearly stagnant ice sheet, cross the washboard moraines. Regardless of how they were formed, the abundant washboard moraines on the Grace City ground moraine leave no doubt of the generally southeasterly flow of the latest ice over the area.

An elliptical-shaped topographic high referred to here as Egg Lake Hill, is found in sections 14 and 15, T. 149 N., R. 72 W. over about a half-square-mile area. It is about 4000 feet long, 2000 feet wide, and 75 feet high. Some gravel is exposed in a roadcut on the northern edge of Egg Lake Hill, but clayey till is the principal sediment at the surface. Associated with the hill is a deep kettle occupied by Egg Lake at an elevation more than 200 feet below the crest of Egg Lake Hill. This situation is nearly identical to several features on the Heimdal end moraine of Eddy County; that is, deep kettles located immediately on the upglacier side of high hills. Perhaps Egg Lake Hill and similar hills in northwest Eddy County, were formed when the ice scooped material from one area and dumped it a few thousand feet away.

The till of the ground moraine is calcareous, silty to clayey, yellowish gray (5Y 7/2) when dry and moderate olive-brown (5Y 4/4) when wet. Boulders and cobbles are absent to scarce at the surface. Some exposures of till in the NE¼, sec. 32, T. 149 N., R. 68 W. and in the west half of sec. 21, T. 149 N., R. 69 W. reveal a horizontal fissile structure similar to stratification that suggests lodgement till. It contains highly decomposed granitic pebbles and is more compact than the massive till that comprises most of the ground moraine. Although this till may be lodgement till, it seems equally possible it is a till older than the surficial Grace City drift that is simply not covered so deeply in that area. This would explain both the unusual compactness and highly weathered aspect of the deposit.

Eskers and disintegration ridges—Numerous eskers and disintegration ridges occur over much of the Grace City drift of Wells County. Eskers are sinuous ridges, sometimes several miles long but commonly discontinuous, and they sometimes follow valleys. They normally have irregular crests with few surface boulders and are composed chiefly of washed drift, with gravel most common. Till disintegration ridges are rectilinear, circular, or arcuate deposits of drift, chiefly till, which form in depressions between blocks of stagnant glacier ice. They can form through mass movement from above when material on the ice slides into the depressions or they may form by squeezing from below.

The unusual abundance of eskers and disintegration ridges indicates the Grace City ice probably stagnated over a large area of Wells County. Meltwater flowing through cracks, trenches and possibly tunnels in the stagnant ice deposited the many ridges now found on the till plain (pl. 1). Many of these ridges contain at least some stratified deposits, but only till was found in others. Although it is impractical to discuss all of the ridges in this report, some of the more interesting should be emphasized.

The longest ridge in the county extends about 12 miles east from a point 3 miles north of Fessenden. This segmented, 20- to 25-foot-high ridge lies almost entirely within the valley of the James River and contains gravel in many places. Its top is flat, 75 to 150 feet wide and covered by till and boulders. Its overall aspect resembles the "tunnel valleys" described by Wright (1964, p. 4-5) although it is not clear whether it formed in a similar manner. A feature in Foster County much like this ridge is described by Bluemle (1965, p. 27) but its origin is also obscure.

A 9-mile-long gravel ridge is transected by the Sheyenne River about 3 miles northeast of Harvey (pl. 1). This 5- to 20-foot-high ridge is paralleled in places by a valley that may have formed at the same time. On its northwest end the ridge becomes buried by sand and gravel deposited by Martin ice meltwater. Gravel was found in the only pit on the ridge.

A complex of gravel-cored ridges occurs in a zone beginning 4 miles northwest of Fessenden and extending to Heaton. Most of the individual ridges are less than 2 miles long and most of them are located in a narrow band of outwash that marks the edge of the stagnant Grace City ice at a late stage of its existence. At a pit in one of the ridges (SW¼, sec. 32, T. 148 N., R. 70 W.) a soil profile developed on gravel is overlain by stratified sand, gravel and windblown sand. The elevation of the buried soil is below the surrounding land surface so it may have developed prior to the deposition of the overlying ridge.

A 40-foot-high ridge in section 35, T. 149 N., R. 72 W. and sections 3, 4 and 10, T. 148 N., R. 72 W. is up to 1250 feet wide and cored with sand and gravel. Exposed in a pit in the SE¼, sec. 35, T. 149 N., R. 72 W., is a buried 3-foot-thick soil profile that is developed on gravel typical of the ridge. The soil is overlain by 1 to 5 feet of stratified gravel with till in places, especially on top of the overlying gravel. Some chunks of soil are included in the overlying till. This soil is elevated above the surrounding terrain and most difficult to account for. Its A horizon thickness of 3 feet presumably indicates an extended interval of time, perhaps several hundred years may have been required to develop it.

A 6-mile-long esker occurs in sections 11 and 13, T. 149 N., R. 70 W. and sections 17-22, T. 149 N., R. 69 W. (fig. 14). This esker is 10 to 20 feet high, 250 feet wide and is contained in a valley. It is composed of fine, clean sand and capped by 3 to 5 feet of highly compacted clayey till. The present interpretation is that this situation does not necessarily imply overriding. Saturated till probably slid from the ice onto the ridge as it formed.

Kames—Kames, as defined by Holmes (1947, p. 248) are "mounds composed chiefly of gravel or sand, whose form has resulted from original deposition modified by any slumping incident to later melting of glacial ice against or upon which the deposit accumulated." The kames of Wells County fit this description.

Figure 14. Photograph of esker. View is east-southeast from 0.5 miles east of the northwest corner of Section 13, T. 149 N., R. 70 W. Photo by Ron Kresl.

An 80-foot-high hill 2 miles south of Sykeston that contains at least some gravel is probably a kame. This kame is part of a small end moraine (p. 21) and may have been overridden by the Grace City ice. It is capped by till and is slightly elongate toward the south.

A group of 3 gravel hills in section 24, T. 149 N., R. 73 W. are about 30 to 40 feet high and associated with a complex of eskers and terraces along the Sheyenne River (pl. 1).

PROGLACIAL LANDFORMS

Outwash plains—Outwash is washed and stratified drift deposited by meltwater flowing in streams beyond a glacier margin; an outwash plain is a broad unit of outwash.

A small outwash plain south of Fessenden (pl. 1) is underlain by thin gravel and sand with intervening areas of till. Its elevation is higher than the ground moraine to the northeast, so the Grace City ice must have bordered it there. Relief on the outwash plain is generally less than 10 feet in a mile. Some sand and gravel is also present to the east, but it is less continuous and not shown on the map. The southwest boundary of the outwash is marked by a rise in the land surface that can be traced as a sort of low "escarpment" all the way from the vicinity of Sykeston to near Harvey (pl. 1).

A larger outwash plain occurs north of Bowdon adjacent to the Missouri Coteau (pl. 1). This outwash, also discontinuous, may have been derived in part from meltwater flowing from the Missouri Coteau but most of it was probably derived from the Grace City ice. Its surface is covered by post glacial alluvial fans in places. Because elevations on the outwash plain are variable, it is difficult to determine in which direction the meltwater flowed, although on the northeastern-most part of the plain it must have flowed southeast, parallel to the adjacent Grace City ice. The outwash is probably slightly older than that near Fessenden, as the ice had not yet retreated that far. Generally, the gravel of this outwash plain is of poor quality with considerable clay and scattered areas of laminated silts that indicate the presence of ponded water. In sections 27, 34 and 35, T. 148 N., R. 73 W., is a lake plain having rather indefinite boundaries. Lake sediments are present elsewhere, but it was impossible to define their limits.

The largest outwash plain in the county is in the Harvey area and it is quite complex. Two levels are associated with the plain; the upper, older level was deposited by the Martin meltwater and the lower, younger level by water from later glacial activity in counties to the northwest of Wells County. The higher part of the outwash plain slopes from an elevation of about 1625 feet at the edge of the Martin end moraine to about 1600 feet southeast of Harvey. The lower part is confined mostly to broad trenches and terraces along the Sheyenne River and is mostly slightly lower than 1600 feet in elevation except along the James River where it is a little higher. In places it is difficult to distinguish the two levels because they have been modified by recent erosion and wind deposition. The lithologies are about the same beneath both levels, that is, coarsely stratified sand and gravel.

Meltwater trenches—In Wells County, water flowed from the margin of the melting glacier through a complex system of meltwater trenches. Because the regional slope is northeastward, the meltwater tended to flow that way but, due to the presence of the Grace City glacier, it was diverted southeastward along the margin of the ice. Therefore, many of the meltwater trenches were originally formed as ice-marginal channels. When the ice front retreated northwestward, the water flowing in these southeast-trending trenches was free to flow northeastward again, parallel to the regional slope. Because the ice wasted only gradually, the meltwater once again became diverted by the ice and formed a new ice-marginal trench further to the northeast.

Most of the meltwater trenches of Wells County have only small amounts of associated outwash sediments. At least one trench, the James valley north of Fessenden, contains an associated esker. Wright (1964, p. 5), suggested that trenches of this type may have been eroded by water under hydrostatic pressure flowing beneath the ice. When the overlying ice ablated, the superglacial drift may have been lowered or washed into the trench partially filling it and burying the outwash sediments that might have been present. The till bottoms of some of the trenches may have resulted in this way.

The several meltwater trenches of Wells County include the Sheyenne River valley, the James River valley, the Heimdal diversion trench, and the valleys of Pipestem and Little Pipestem Creeks. There are also innumerable smaller trenches.

The largest meltwater trench in the county is the one that now carries the Sheyenne River (fig. 15). The terraces on the walls of the trench, especially well-developed in the Harvey area, are about 40 feet above the present floor of the valley (fig. 16). The elevations on the terraces decrease from about 1600 feet south of Harvey to about 1570 feet southeast of Wellsburg. They probably are parts

Figure 15. Sheyenne River meltwater trench. View is north in section 24, T. 149 N., R. 73 W. Photo by George Faigle.

Figure 16. Terrace along the Sheyenne River meltwater trench. NW¼, sec. 13, T. 150 N., R. 71 W. Photo by George Faigle.

of the floor of an ancestral trench that formed about the same time as the lower of the two outwash plains in the Harvey area.

The original stream that flowed at the elevation of these terraces was probably continuous with the Heimdal Diversion trench along the southern margin of the Heimdal end moraine. It was not until later, when water from the ice-marginal Souris and DeLacs Rivers was available, that the deeper trench was cut below the terraces.

Considerable gravel is present at several locations on terraces in the Sheyenne River meltwater trench. Gravel is particularly abundant in the NW¼, sec. 13, T. 150 N., R. 71 W. on one of the terraces. In the Heimdal Diversion trench considerable good gravel remains; water from Glacial Lake Souris that cut the Sheyenne River valley did not flow through the Heimdal Diversion trench and therefore did not remove the gravel there as it did in the Sheyenne River valley.

The James River meltwater trench follows a highly irregular course through Wells County (pl. 1). It has no significant associated terraces and in most places it is floored with till; only insignificant amounts of gravel are associated with it. The trench is generally less than 20 feet deep and from ⅛ to ¾ mile wide. Boulders are concentrated on the floor in some places, probably due to removal of the fine fraction by washing from the till.

The Pipestem-Little Pipestem Creek meltwater trenches were originally formed as ice marginal trenches between the Grace City ice and the front of the Missouri Coteau. A kame terrace with associated gravel deposits in sec. 36, T. 146 N., R. 69 W., and sec.

6, T. 145 N., R. 68 W. and sec. 1, T. 145 N., R. 69 W. was deposited by water that flowed in the trench during an early stage of its existence. Considerable supplies of excellent gravel are associated with parts of the meltwater trench system adjacent to the Coteau escarpment.

POSTGLACIAL LANDFORMS

Lake plains—West of Fessenden in the northeast part of T. 148 N., R. 71 W. is a 1.5 square-mile area mapped as a recent lake deposit. Two well-developed boulder pavements indicate a former shoreline in sections 12 and 13, T. 148 N., R. 71 W. The sediments in the basin are thin, discontinuous layers of light olive-green lake clays and silts (5Y 5/2, wet) with sand stringers.

Egg Lake (secs. 9 and 10, T. 149 N., R. 72 W.) is surrounded by a strandline 20 feet higher than the present lake surface. Between the two levels is a fine yellowish-gray sand (5Y 7/2, wet) on which a soil has developed indicating that the 20-foot drop in lake level may not be a recent event but possibly even one that occurred soon after the retreat of the Grace City ice sheet.

Windblown sand and silt—Deposits of windblown sand and silt occur throughout Wells County, but they are of limited extent and have not been mapped in detail.

Heimdal-Martin Phase

History—Although the exact relative ages of the Heimdal and Martin end moraines and the landforms associated with them are not known, it is convenient to treat them as being penecontemporaneous in Wells County. Further work in counties to the north, particularly Pierce and Benson, will be necessary to determine the relationships of the two end moraines.

At some time prior to the deposition of the Heimdal and Martin end moraines, a large part of the glacier in north-central Wells County stagnated (fig. 17) resulting in an area of thin stagnant ice that became riddled with innumerable eskers, disintegration ridges and asssociated meltwater channels. The presence of these innumerable ice-contact features is probably the best evidence for such a body of stagnant ice. Not nearly so many ridges would have been preserved if the ice had been active; moving ice tends to obliterate ice-contact features. Most of the larger of these ice-contact features are shown on plate 1 but many smaller ones are also present. As this stagnant ice wasted, the meltwater flowing along its margins and over its surface deposited widespread, but thin, accumulations of sand. Much of this sand was not mapped because it is too thin and discontinuous.

The Martin and Heimdal end moraines may represent a slight readvance of the ice. It is not known just where the active ice margin re-established itself when the large area of ice became stagnant in north-central Wells County, but it was probably not a great distance north of the present Heimdal and Martin end moraines.

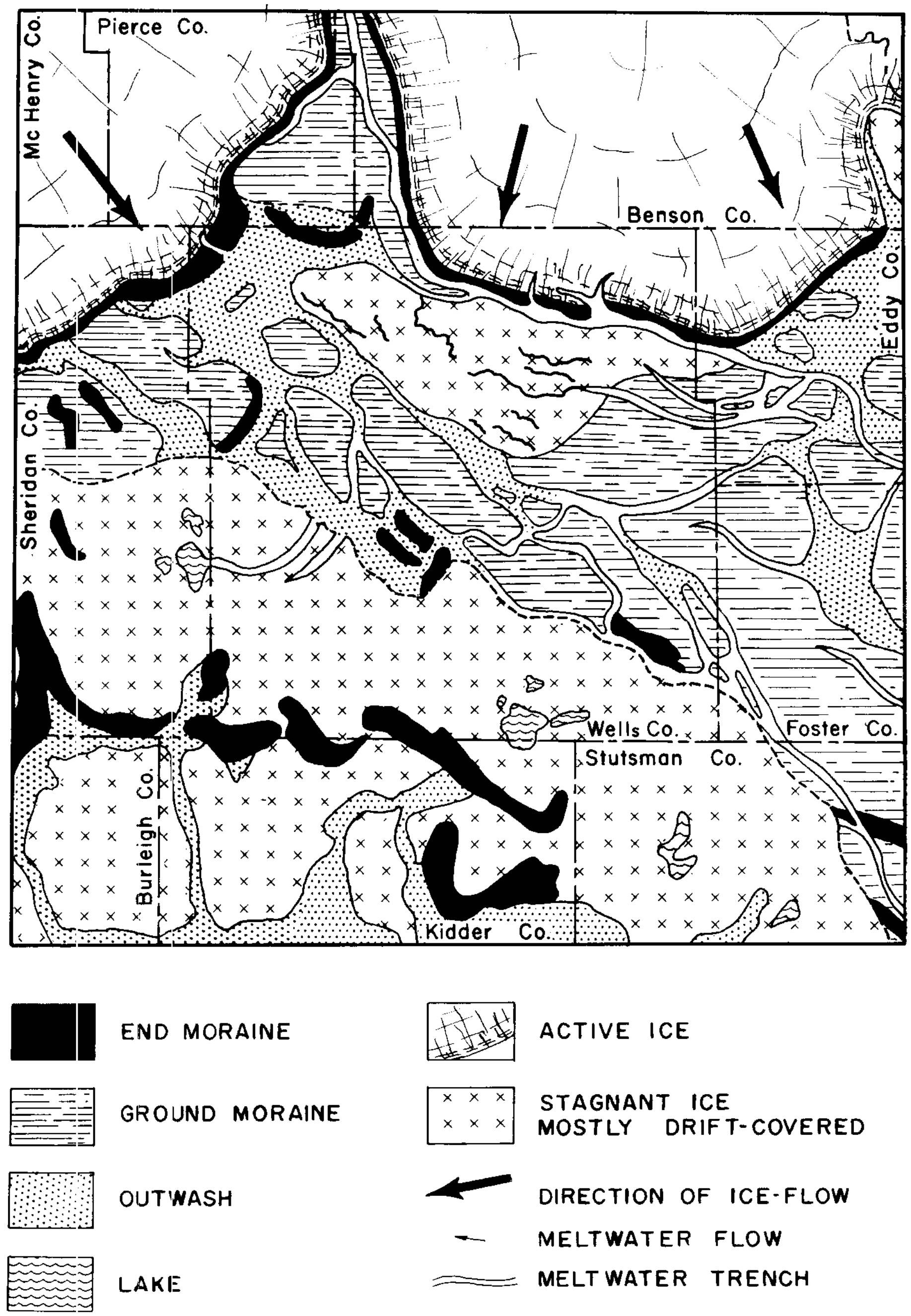

Figure 17. Heimdal-Martin phase. During this phase the Heimdal and Martin end moraines were deposited. Abundant ice-contact features developed in the area covered by stagnant ice in northern Wells County.

The primary factor influencing this shift in ice flow directions was probably a regional thinning of the glacier coupled with the presence of bedrock highs to the north, particularly the Turtle Mountains. When the glacier became too thin to override the Turtle Mountains, it split into two lobes, the Leeds on the east and the Souris on the west (Lemke, 1958, p. 51). The Leeds ice deposited the Heimdal end moraine and the Souris ice deposited the Martin end moraine.

The small loop of end moraine on the Wells County line between the Heimdal and Martin end moraines has already been discussed. It is possible this end moraine is recessional and was deposited slightly before the Martin end moraine but because its surface appears to be streamlined it seems more likely it was deposited much earlier, perhaps during the first advance of late Wisconsinan ice over the area. The position of the end moraine coincides with the ice margin along which the now buried Heimdal trench formed. The loop of end moraine may have formed at the same time the trench was being cut, perhaps by meltwater from the same ice that deposited the end moraine.

Heimdal drift—Drift of the Heimdal phase covers about 10 per cent of Wells County. It consists of the Heimdal end moraine and small amounts of associated ground moraine along with some minor meltwater trenches. The name "Heimdal" was first applied to the Heimdal end moraine by Branch (1947, p. 6) for the village of Heimdal in northeast Wells County.

Martin drift—Drift of the Martin phase covers about 15 per cent of Wells County. It consists of the Martin end moraine and a large outwash plain in the northwestern part of the county. The name "Martin" was first applied to the Martin end moraine by Lemke and Colton (1958, p. 49) for the village of Martin in northeast Sheridan County.

GLACIAL LANDFORMS

Heimdal end moraine—The Heimdal end moraine covers most of T. 150 N., Rs. 68 and 69 W. and about 30 per cent of R. 70 W. It ranges in width from 2 to 5 miles and extends northward into Benson County and eastward into Eddy County. The topography of the end moraine is variable, ranging from close-spaced ridges as in secs. 13 and 24, T. 150 N., R. 69 W. to broad, flat sags as in secs. 10 and 15, T. 150 N., R. 68 W. Local relief averages from 40 to 80 feet in a square mile, but up to 150 feet near Black Hammer Hill in section 8, T. 150 N., R. 68 W. Boulders and cobbles are abundant on the Heimdal end moraine.

The drift of the end moraine consists mostly of clayey and sandy till that ranges in color from dark yellowish-brown (10YR 4/2) to moderate olive-brown (5Y 4/4). Much of the till is loose and fissile with decomposed granitic pebbles.

The lineations on the end moraine seem to outline two loop-like segments, one on either side of Black Hammer Hill which forms an apex around which the lineations are grouped. This may mean that Black Hammer Hill is a bedrock high that split the ice into two small lobes, but no test hole data are available to either confirm or deny the existence of a bedrock high here.

Martin end moraine—The Martin end moraine crosses the extreme northwest corner of Wells County. It is a very extensive feature, shown by Lemke, Colton and Lindvall (1963) to extend from the Turtle Mountains on the northeast to somewhere west of Minot on the west. The Martin end moraine marks a recessional phase of the Souris ice lobe which flowed southeastward between the Turtle Mountains and the Missouri Coteau.

In Wells County the Martin end moraine is a prominent range of hills with local relief of about 50 feet in a square mile. The till comprising the end moraine is clayey, calcareous, and yellowish-gray (5Y 7/2, dry) to light olive-brown (5Y 5/6, wet). Considerable amounts of associated sand and gravel occur sporadically as well as near small meltwater channels in the end moraine. Boulders and cobbles are abundant on the surface.

Ground moraine—The small areas of ground moraine located north of the Heimdal end moraine have an average relief of 15 to 20 feet in a square mile, but some hills rise as high as 40 feet above surrounding areas. The topography is characterized by rounded hills that appear to be streamlined suggesting that ice overrode them at one time. Washboard moraines indicate that the ice receded northward. The till of the ground moraine is silty and light olive-gray (5Y 5/2) to dark yellowish-brown (10Y 4/2). Boulders and cobbles are numerous on the surface.

Eskers—Two small ridges that may be eskers are located in secs. 5 and 6, T. 150 N., R. 73 W. They are closely associated with a meltwater trench; one rises from the trench floor. A pit in one of the eskers contains boulders up to 3 feet in diameter along with chunks of fine, cross-bedded sand that must have been frozen when they were deposited there.

PROGLACIAL LANDFORMS

Meltwater trench—The Sheyenne River valley extends through the northeast corner of Wells County. It is flanked by prominent gravel and sand terraces that occur at an elevation of 1480 feet, approximately 60 feet above the floor of the valley. These terraces correspond to the Grandfield terraces discussed by Bluemle (1965, p. 62). They are unrelated to the terraces along the Sheyenne River near Harvey because they are at least 100 feet lower in elevation. Further work needs to be done on the North Fork of the Sheyenne River in Benson and Pierce Counties to the northwest before the drainage history can be adequately explained.

An excellent southeast-trending meltwater trench is located in secs. 5, 6 and 8, T. 150 N., R. 73 W. It is about 1,600 feet wide, 15 feet deep and it contains large amounts of sand and gravel. The trench connects with the outwash plain in front of the Martin end moraine.

Lake plains—Three feet of unfossiliferous, stratified lake silts overlie fine sand on the 1480-foot terrace of the Sheyenne valley in the NE¼, sec. 11, T. 150 N., R. 68 W. Two feet of gravel overlie the lake sediments. Similar lake sediments were found in several locations along the Sheyenne valley in Eddy County. They were probably deposited during a temporary damming of the channel, perhaps as the result of a landslide somewhere downstream from the area. The lake sediments are always found at an elevation of about 1480 feet.

ANALYSIS OF THE SURFICIAL DRIFT

Analysis of Till Grain Size—Samples of till were taken from 144 localities in Wells County at depths of 3 to 4 feet beneath the surface. The percentages of sand, silt and clay were determined for each sample by sieving out the sand and gravel and analyzing the remaining fraction with a hydrometer to determine the silt-clay ratio. Gravel was considered to be anything over 840 microns in diameter (it would not pass a screen with openings of 840 microns), sand included sediment between 63 and 840 microns, silt included sediment between 4 and 63 microns and clay included everything smaller than 4 microns in diameter. Table 1 shows the average of the clay, silt, and sand for each of the drifts studied.

TABLE 1

	SAND %	SILT %	CLAY %
STREETER TILL 44 samples	29	38	33
GRACE CITY TILL 91 samples	39	36	25
HEIMDAL TILL 9 samples	26	46	28

Average sand-silt-clay ratio of surface tills in Wells County

The slightly higher clay percentage in the Streeter till and the slightly higher sand percentage in the Grace City till may reflect the bedrock over which the ice sheets moved. The Streeter drift was deposited by ice that came from the northeast and therefore moved over Pierre shale bedrock whereas the Grace City drift was deposited by ice that came from the northwest, moving over Fox Hills and Hell Creek sandstones. The Pierre shale probably supplied the larger clay fraction to the Streeter drift, and the Fox Hills and Hell Creek formations the larger sand fraction to the Grace City till. There is, however, a wide divergence in size ratios and the averages may not be a true representation of the actual size distribution. In Eddy and Foster Counties to the east, the size compositions of the Grace City and Heimdal drifts correspond remarkably well to the same drifts in Wells County. Additional samples from other counties need to be analyzed before it can be determined whether there is a systematic particle size distinction among the various drifts.

Analysis of Boulders on the Surface—The percentages of the various lithologic types of boulders were determined at 27 locations in Wells County. Igneous rocks represented well over 50 percent of the total boulders on each of the drift sheets, but no real differences in the rock-type distribution were found for any particular part of the county.

Analysis of Pebbles in the Till—Table 2 shows the percentages of the three most common types of pebbles in till throughout Wells County. Samples of 100 pebbles each collected at 31 locations are grouped according to the drifts from which they were taken. The pebbles are grouped in Table 2 into igneous plus metamorphic pebbles, carbonate pebbles and local bedrock pebbles. Carbonate pebbles include limestone and dolostone as well as chert which was probably derived from Paleozoic carbonate formations. Local bedrock includes shale and sandstone.

TABLE 2

	IGNEOUS AND METAMORPHIC %	CARBONATE %	LOCAL BEDROCK %
STREETER TILL 7 samples	38	50	12
GRACE CITY TILL 17 samples	35	56	9
HEIMDAL TILL 6 samples	42	49	10
MARTIN TILL 1 sample	70	29	1

Surface pebble composition of Wells County tills

Although the Martin till has a higher igneous and metamorphic pebble concentration than the other tills, it should be pointed out that the Martin till was sampled at only one location. This is insufficient data to draw conclusions from. Carbonates are far more abundant in the pebble size than in the boulder size. This presumably reflects a greater resistance on the part of the crystalline rocks to mechanical disintegration as opposed to carbonates and other sedimentary types.

ECONOMIC GEOLOGY

Sand and Gravel

Sand and gravel occur as ice-contact deposits, beneath river terraces, underlying outwash plains and as channel deposits. Some deposits have been exploited for road construction material, but much more extensive deposits remain. The quality varies inversely with the shale content and the shale content is commonly high, so the deposits have their economic limitations.

The best sources of sand and gravel are the well-sorted sediments of the terraces along the Sheyenne River valley, particularly in secs. 13 and 14, T. 150 N., R. 71 W. This terrace deposit is being mined but considerable supplies remain. Other potential sources are the eskers and some of the disintegration ridges throughout the county. In addition, several large kames on the Missouri Coteau contain appreciable amounts of sand and gravel.

Ground Water

The ground water resources of Wells County will be discussed in detail in Parts II and III scheduled to follow this publication. For this reason, only a few general observations will be included here.

Most of the water used by farmers in Wells County comes from gravel and sand aquifers within the glacial materials. Of particular importance are the deposits in the buried Heimdal trench in the northern part of the county (pl. 3). The buried gravel deposits in the preglacial Knife and Cannonball valleys and their tributaries may also contain important supplies of water.

The Sheyenne River meltwater trench is underlain by deposits of permeable gravel and sand that yield appreciable supplies of water. The town of Harvey obtains its water supply from these gravels through a system of collection wells in sec. 21, T. 150 N., R. 72 W. Similar collection wells placed elsewhere in the meltwater trench should also yield significant supplies of ground water.

Other meltwater trenches such as those in which Rocky Run and the Little Pipestem Creek flow, may be underlain by water-bearing gravels. The town of Fessenden obtains its water from a well in the SE¼, NE¼, sec. 4, T. 149 N., R. 70 W. The water is obtained from a sand and gravel aquifer at a depth of 150 feet. This aquifer may be related to the meltwater trench it underlies, or it may be in the Heimdal trench deposits. Most of the gravels in the Heimdal aquifer lie at depths greater than 150 feet so probably the Fessenden water supply comes from a source unrelated to these gravels.

In addition to the above mentioned ground water sources, the Carrington aquifer underlies part of eastern Wells County near Cathay in T. 148 N., R. 68 W. In general, any extensive surface deposit of sand and gravel should be investigated for its ground water potential. The outwash plains in northwestern Wells County and along the front of the Coteau in T. 147 N., Rs. 71 and 72 W. may contain appreciable supplies of water.

Surface Water

All the streams in Wells County are ephemeral and would probably contain very small amounts of surface water during most of the year were it not for the numerous small dams along the streams. The ephemeral streams include the Sheyenne and James Rivers, Rocky Run, Pipestem Creek and Little Pipestem Creek. No perennial lakes exist north of the Missouri Coteau in Wells County but there are numerous ones on the Coteau. These are mostly saline, however, due to their impervious till floors.

Springs are common on the north face of the Missouri Coteau, especially near Hawks Nest in the southeast corner of the county. Some springs also occur along the valley walls of the Sheyenne River.

Soil

The entire area has soil of the Chernozem great soil group. The most common soil types are those associated with the Barnes and Svea soils. These soil types are formed in areas of end, dead-ice and ground moraine and reflect the general morphology of the county. They are black, silty loams and clay loams essentially unleached of carbonates.

Petroleum

Sixteen wildcat wells have been drilled for oil in Wells County as of July 1, 1966. All the holes were dry.

According to Ballard (1963, p. 38) the Carrington Shale facies provides two types of stratigraphic traps that are potential producers of petroleum. The first of these, the facies change of the Bottineau carbonates in an updip direction into the Carrington Shale occurs along a north-south line from western Wells County to central Emmons County. The other occurs in eastern Wells County and to the south where the Carrington Shale seals the truncated Birdbear and Duperow Formations. The Duperow Formation produces oil in western North Dakota and the Birdbear has excellent porosity so Wells County does have potential as a possible future petroleum producer.

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