NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, *State Geologist*

BULLETIN 44

NORTH DAKOTA STATE

WATER CONSERVATION COMMISSION

MILO W. HOISVEEN, *State Engineer*

COUNTY GROUND WATER STUDIES 5

GEOLOGY AND GROUND WATER RESOURCES

of Eddy and Foster Counties, North Dakota

PART I — GEOLOGY

by

JOHN P. BLUEMLE

GRAND FORKS, NORTH DAKOTA

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

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The Geology of Eddy and Foster Counties

by John P. Bluemle

ABSTRACT

Eddy and Foster Counties are in east-central North Dakota, high on the eastern flank of the Williston Basin. They are underlain by 3200 to 4300 feet of Paleozoic and Mesozoic rocks that dip gently to the west. The uppermost formation, the Cretaceous Pierre Shale, lies directly beneath the glacial drift and crops out in the valleys of the James and Sheyenne Rivers. Glacial drift that covers the entire area averages about 150 feet thick but in certain buried valleys it is as much as 400 feet thick.

The two-county area lies mainly within the Drift Plains district of the Central Lowland province; a small area of southwest Foster County is in the Missouri Coteau district of the Great Plains province. The Drift Plains part of Eddy and Foster Counties is characterized by a surface of flat to gently rolling topography that is rough on the four end moraines and smoother on the ground moraines and outwash plains. Associated with these major landforms are numerous washboard moraines, drumlins, and ice disintegration features. The Missouri Coteau district of southwest Foster County is characterized by a hilly surface on dead-ice moraine.

Surficial deposits are chiefly till and outwash, but proglacial and postglacial lake sediments, colluvium, dune sand and recent alluvium are also present. Studies of the color, boulder and pebble lithology, and grain size of the till revealed no significant variations in the physical characteristics of the surficial drift over the two counties.

As the late Wisconsinan glacier in the east-central North Dakota area thinned and receded, it was increasingly affected by topographic highs over which it flowed. Thick ice that had been flowing unaffected by the underlying bedrock highs became blocked by those highs when it had thinned substantially, causing lobation as the ice was forced to flow around the highs. In east-central North Dakota evidence for such lobation is graphically illustrated by the irregular pattern of the end moraines. One of the end moraines, the McHenry end moraine, was deposited on stagnant ice; part of it collapsed when

the stagnant ice melted. After active ice had left the area, meltwater from glacial Lake Souris continued to flow through the trenches of the Sheyenne and James Rivers, deepening them and forming extensive terraces.

The most important economic resources in Eddy and Foster Counties 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.

INTRODUCTION

Purpose and Scope of Study

This report is a descriptive and interpretive analysis of the geology of Eddy and Foster Counties, which comprise about 1291 square miles in east-central North Dakota (fig. 1). It is one of a series of county reports carried on by the North Dakota Geological Survey in cooperation with the North Dakota State Water Conservation Commission and the United States Geological Survey. Reports dealing with the ground water basic data and ground water and chemical quality of water will be published separately.

Primary objectives of this study were: 1) to provide a detailed map of the geology of the area; 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

Foster and Eddy Counties were mapped during the 1962 and 1963 field seasons, respectively. Field information was plotted directly on topographic maps of the 7 1/2 minute series, scale 1:24,000, published by the United States Geological Survey. Aerial photograph stereopairs, scale 1:63,360, taken in 1952 were available for both counties. Semi-detail land classification maps prepared by the Bureau of Reclamation are available for the western third of Foster County. These were useful for refining some of the geologic contacts.

Lithologic information was obtained primarily from road cuts and shallow holes dug with shovel and soil auger. Because of the flat terrain and a lack of adequate exposures in the area, hundreds of holes and trenches were dug, mostly to less than five feet, to obtain data. Information on deposits at greater depth was obtained chiefly from test holes contracted for by the Water Resources Division of the United States Geological Survey. All samples of till were obtained with a soil auger with an extendable shank which allowed depths of ten feet to be reached. Colors of sediments were determined by comparison with the Rock Color Chart (Goddard and others, 1951). All passable roads in the area were traversed by field vehicle; less accessible areas were covered on foot.

Information on the geology beneath the glacial deposits was obtained by examining cuttings from exploratory oil wells in the two counties. Electric logs of the wells were also studied.

Acknowledgements

Appreciation is extended to those individuals and agencies who have contributed to this study. Dr. Wilson M. Laird, State Geologist, made helpful suggestions in the field and guided early phases of manuscript preparation. Samuel J. Tuthill, formerly of the North Dakota Geological Survey, made all fossil identifications. Miller Hansen, former Assistant State Geologist, guided early field phases of the work.

Roger Schmid and Larry Froelich of the North Dakota State Water Conservation Commission provided lithologic descriptions of the test hole cuttings. Henry Trapp of the United States Geological Survey supplied test hole data and other valuable information.

Finally, I extend my appreciation to the landowners of Eddy and Foster Counties who were very cooperative in providing data on private wells and in allowing access to their property.

Previous Work

The most comprehensive summary now available of North Dakota Pleistocene geology is by Lemke and Colton (1958). Their latest interpretation of the State's glacial geology is shown on 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 fifteen-minute quadrangles which extend into northern Eddy County, and those by Aronow (1957, 1963) on the glacial geology of the Devils Lake region and along the Sheyenne River. The glacial geology of Stutsman County, south of Foster County, has been described by Winters (1963). 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 parts of the two counties.

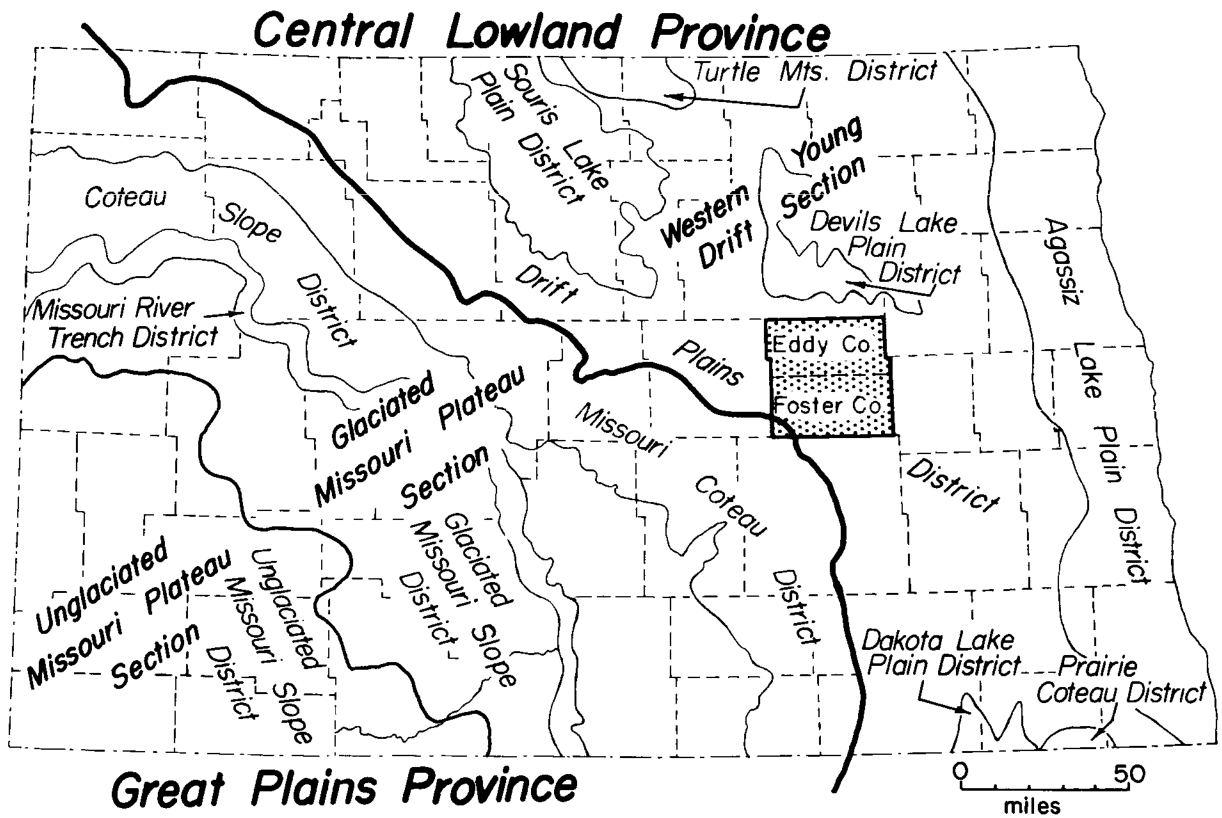

Figure 1. Index map showing location of Eddy and Foster Counties and the phisiographic subdivisions of North Dakota. Modified from Lemke and Colton, 1958, fig. 1 and Clayton, 1962.

GEOGRAPHY

General

Eddy County comprises about 643 square miles in Tps. 148-150 N., Rs. 62-67 W.; Foster County comprises about 648 square miles in Tps. 145-147 N., Rs. 62-67 W. The area is located midway between the Red River and the Missouri River, 80 miles from each; it is bordered on the north by Benson County, on the west by Wells County, on the south by Stutsman County and on the east by Griggs and Nelson Counties.

In 1960 the population of Foster County was 5,361. Carrington, the largest town and county seat, had a population of 2,438. McHenry and Glenfield had populations of 155 and 129 respectively. Other smaller villages in Foster County include Barlow, Bordulac, Grace City, Juanita and Melville. The 1960 population of Eddy County was 4,936. New Rockford, the largest town and county seat, had a population of 2,177. The town of Sheyenne had a population of 423. Other smaller villages in Eddy County include Munster, Brantford and Hamar.

United States Highway 281 crosses Eddy and Foster Counties and serves both Carrington and New Rockford. United States Highway 52 passes through Carrington and State Highways 15 and 7 cross Eddy and Foster counties, respectively, in an east-west direction. In addition to these hard-surfaced roads, State Highways 9 and 20 are all-weather gravel roads. Gravel roads are located on about 90 percent of the section lines; most of these are passable by field vehicle in dry weather.

The main line of the Great Northern Railroad serves New Rockford and branch lines of the Northern Pacific Railroad serve both Carrington and New Rockford. The Minneapolis-St. Paul-Sault St. Marie Railroad serves Carrington.

Climate

The climate of the area is dry-subhumid first (cool) mesothermal (Thornthwaite, 1948, pl.) with a short, cool summer. According to Trewartha, (1961), the area has a humid, continental climate with cool summers. The average annual temperature at Carrington is 40°F., the January average 7°F., and the July average 69.5°F. Recorded extremes are -43° and 116°. Two-thirds of the average annual precipitation of 16.6 inches falls during the 124 day growing season from

April to August. Recorded precipitation extremes at Carrington are 6.52 and 25.27 inches (U. S. Department of Agriculture, 1941, p. 1046). Blizzards occur occasionally during the winter but snowfall is generally scanty.

The prevailing wind direction is from the northwest in all months except June and August when southeasterly winds predominate. The average wind movement during the year is about 10 miles per hour, strongest in the spring months. The northerly latitude causes long daylight hours during the summer thus helping to compensate for the short growing season. Sunshine averages from 45 percent in the

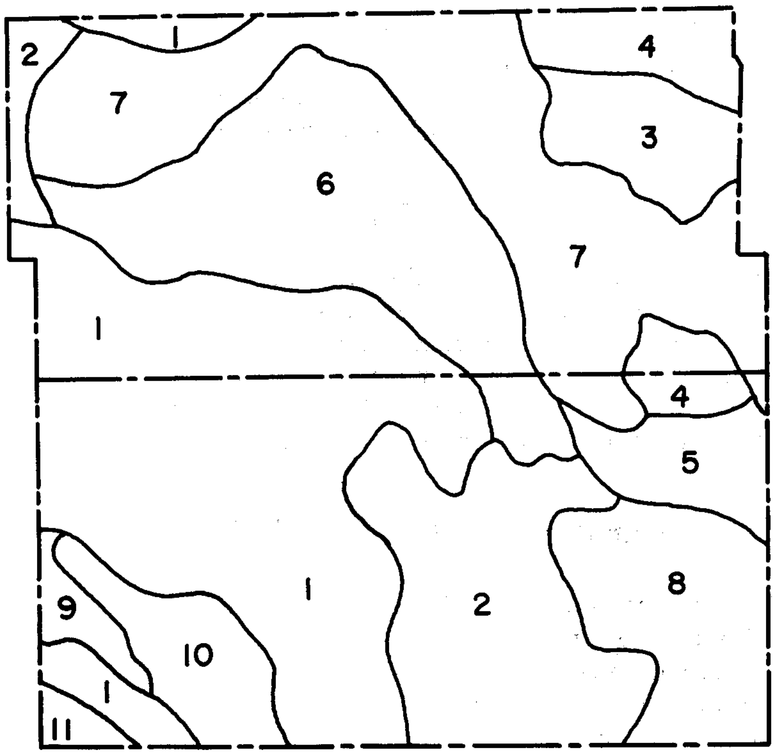

Figure 2. Generalized soil map of Eddy and Foster Counties. Numbers below refer to numbers on map. Adapted from Omodt, and others (1961).

BLACK SOILS OF SUBHUMID GRASSLAND

Loams and clay loams: 1) Barnes-Glyndon; 2) Barnes-Hamerly; 3) Barnes-Svea
Sandy loams and loams with sandy substrata: 4) Hecla-Hamar; 5) Maddock-Barnes
Sandy loams and loams with sandy and gravelly substrata: 6) Renshaw-Divide
Loams — rolling and steeply sloping soils: 7) Barnes-Buse

VERY LIMY SOILS OF SUBHUMID GRASSLAND 8) Hamerly-Svea-Tetonka

ALKALI SOILS 9) Cresbard-Barnes-Cavour; 10) Cresbard-Cavour

SOILS ON STEEP LAND 11) Buse-Barnes

winter to 70 percent in the summer. Relative humidity in the summer averages from 85 percent in the early morning to 50 percent in the late afternoon and during the winter averages about 75 percent day and night.

Native Vegetation

The area is part of a transition zone in which occur tall grasses of the more humid east and short prairie grasses of the western steppe. According to Wills (1963), a gramma and western-wheat association occurs on the drift prairies along with needle-and-thread, Junegrass and Kentucky bluegrass.

Oak and Cottonwood trees occur along streams, particularly in the valley of the Sheyenne River, and Aspen is common in northeastern Eddy County on areas of sand dunes. Wolfberry (buckbrush) is common on hillsides in rough land, particularly on the Missouri Coteau.

Soil

The entire area has soil of the Chernozem great soil group. This soil, mainly the Barnes soil series, is black, silty to sandy loam essentially unleached of carbonates. Some undrained areas, especially south and west of Carrington and in southeastern Eddy County, contain injurious quantities of alkali, chiefly sodium sulphate. Figure 2 shows the generalized soil map of Eddy and Foster Counties.

PRE-PLEISTOCENE STRATIGRAPHY

Approximately 2,800 to 4,200 feet of Paleozoic and Mesozoic rocks lie on the Precambrian basement in Eddy and Foster Counties (fig. 5). The Cretaceous Pierre Formation underlies the glacial drift and is exposed in numerous outcrops along the Sheyenne and James Rivers. Available well samples, cores and core chips, from all 17 oil wells that have been drilled in Eddy and Foster Counties as well as samples from some wells in adjacent counties were studied during the course of this work. The electric logs of all these wells were studied. In addition, North Dakota Geological Survey Bulletins by Hansen (1955), Carlson (1960), Carlson and Eastwood (1962), and Ballard (1963) deal with the geology in areas that include Eddy and Foster Counties.

Eddy and Foster Counties lie on the eastern edge of the Williston

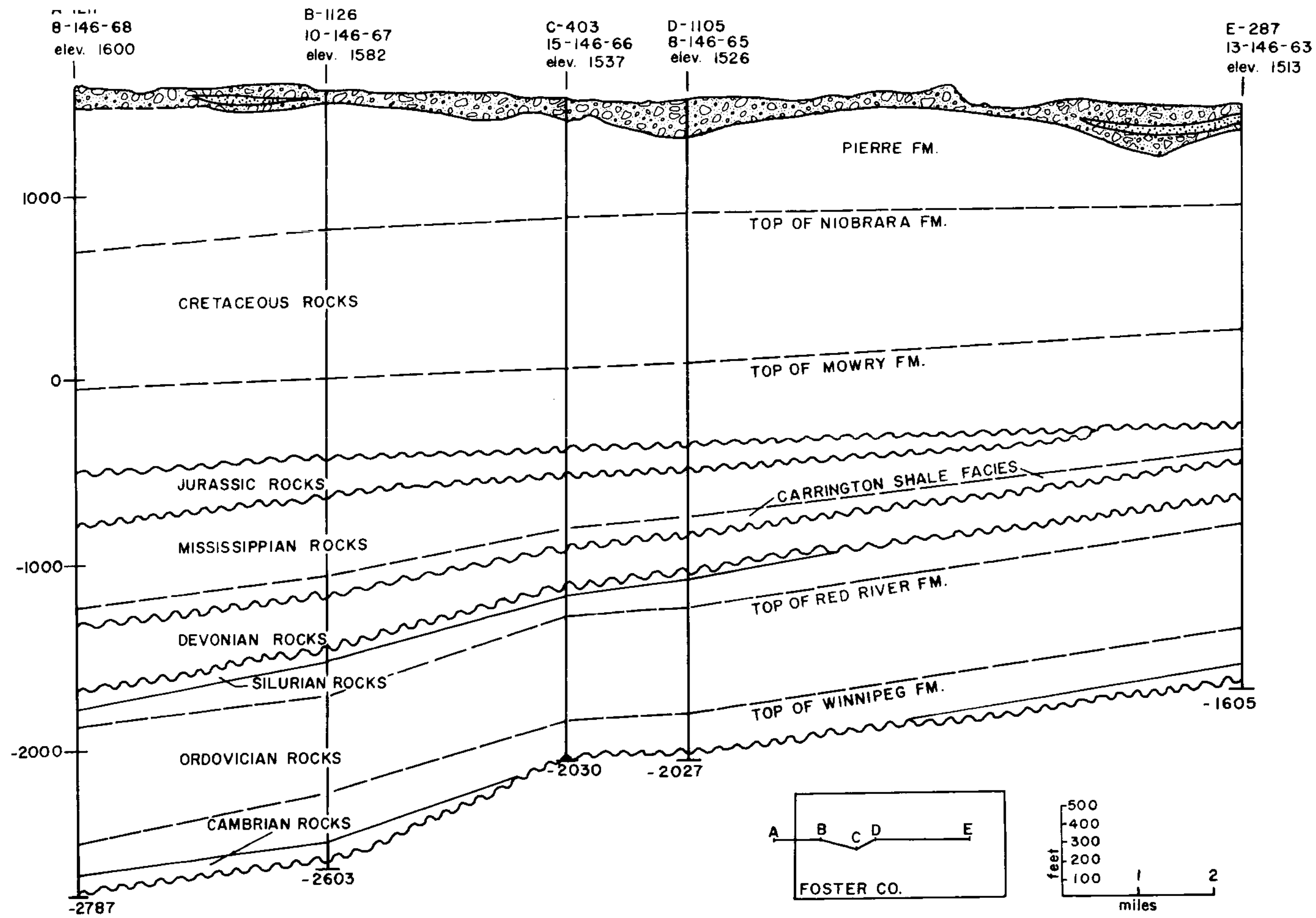

Figure 3. Diagrammatic cross-section of Foster County.

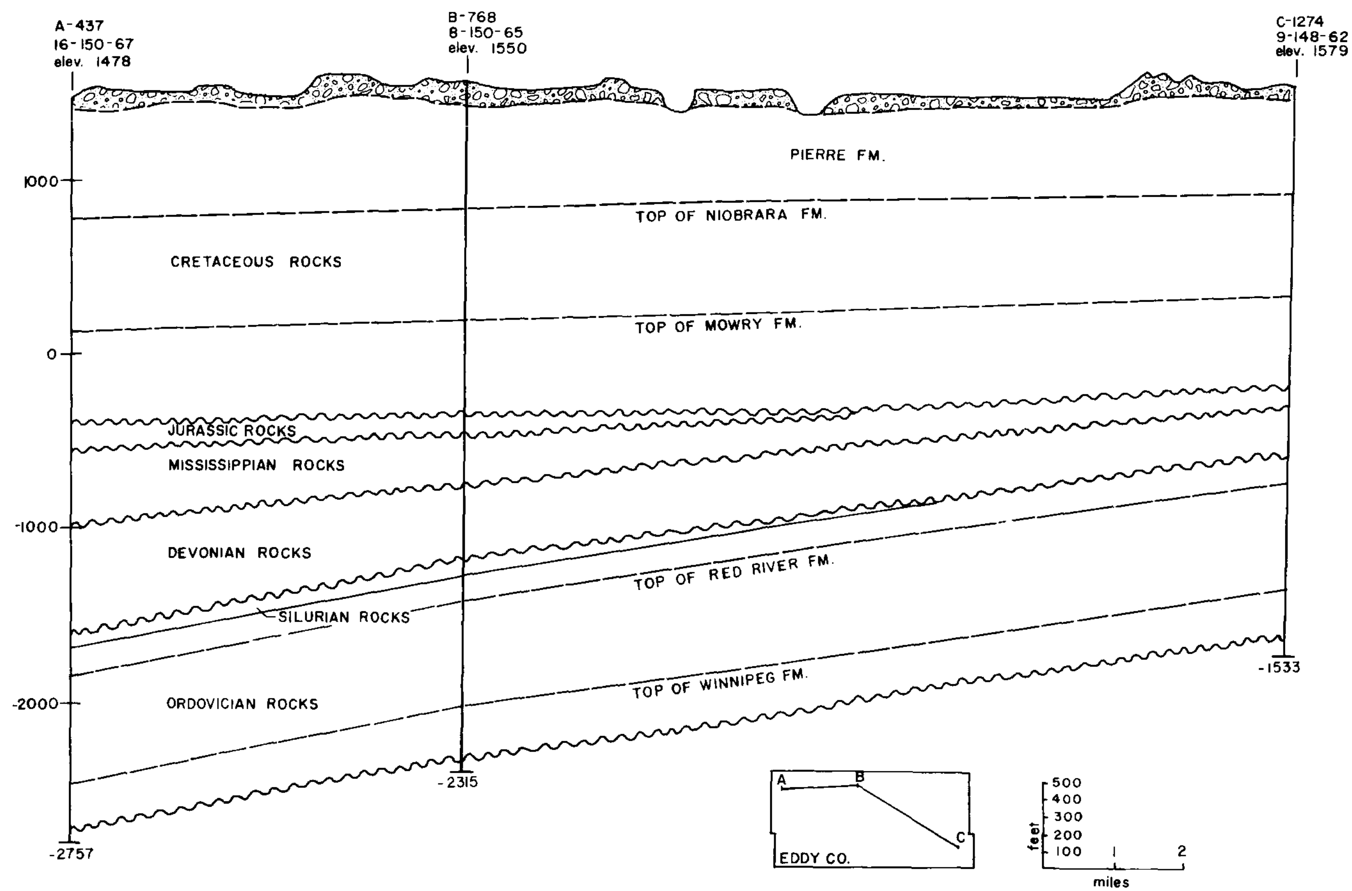

Figure 4. Diagrammatic cross-section of Eddy County.

Basin, so all of the formations have a westerly regional dip (figs. 3 and 4). Most of the formations become thicker westward except near and on the Foster high (Ballard, 1963) which was intermittently active from Precambrian throughout Paleozoic time.

Precambrian

The depth to the Precambrian varies from a minimum of about 2775 feet in southeastern Foster County to a maximum of about 4300 feet in northwestern Eddy County. The westerly regional slope on the Precambrian surface is about 40 feet per mile into the Williston Basin. Of the 11 Precambrian test wells in the area, one penetrated chlorite schist (well E-287), one penetrated serpentinite (well D-1105), and all others penetrated granite. Magnetic anomalies have been noted in adjacent areas (Hansen, 1953; Haraldson, 1953), and these may be caused by similar variations in the lithology of the Precambrian rocks.

Paleozoic

Cambro-Ordovician rocks

The Deadwood Formation of Late Cambrian and Early Ordovician age lies non-conformably on the Precambrian rocks. It ranges from about 40 to 80 feet thick in Eddy and Foster Counties except where it is absent on the structural high in west-central Foster County. It consists of grayish-red (10R 4/2) calcareous, glauconitic to quartzitic sandstone overlain by grayish-red (5R 4/2) silty, glauconitic dolomite and shale.

Ordovician rocks

Ordovician rocks attain a total thickness of about 1000 feet and include the Winnipeg, Red River, Stony Mountain and Stonewall Formations. The Winnipeg Formation lies unconformably on the Deadwood Formation and varies from a minimum of about 90 feet thick in northwestern Eddy County to a maximum of about 220 feet thick in southeastern Foster County. It includes three members. The lower member, absent in places, consists of fine to very coarse, rounded and frosted loose quartz sand with specks of glauconite and sporadic gypsum cementation. The upper two members consist of greenish-gray (5G 6/1) and grayish-red (5R 4/2) slightly calcareous waxy to soft splintery shale.

Conformably overlying the Winnipeg Formation is the Red River Formation. It ranges in thickness from 540 to 590 feet, thickening northwestward except in southeastern and northwestern Foster

County where it is less than 530 feet thick. It consists of light brown (5YR 6/4) to yellowish and very pale orange (10YR 8/2) granular to crystalline, variably porous limestone and dolomite.

The Stony Mountain Formation conformably overlies the Red River Formation. It averages about 130 feet thick and attains a maximum thickness of about 140 feet in the western part of the area. The lower of the two members, the Stoughton, consists of olive gray (5Y 4/1) calareous, sandy shale and light brown (5YR 6/4) sucrosic silty dolomitic limestone. The upper member, the Gunton, consists of grayish-orange pink (5YR 7/2) to very pale orange (10YR 8/2) dense to vuggy calcic dolomite.

Siluro-Ordovician rocks

The Stonewall Formation, within which the Ordovician-Silurian boundary has been tentatively placed by Carlson and Eastwood (1962, p. 9), conformably overlies the Stony Mountain Formation and is conformably overlain by the Silurian Interlake Formation. It averages about 55 feet thick over the area but thickens slightly northeastward. The Stonewall Formation consists of yellowish-gray (5Y 7/2) to very pale orange (10YR 8/2) silty calcic dolomite. Near the erosional limit which is immediately southeast of Foster County, the color varies to pinker shades and red silt is common in the carbonates.

Silurian rocks

The Interlake Formation of Silurian age is present in the northwestern half of Eddy and Foster Counties where, from its erosional limit, it thickens to about 80 feet in north-central Eddy County. Due to post-Silurian erosion, only the lower part of the Interlake is present in the area. It consists of white to yellowish-gray (5Y 7/2) to very pale orange (10YR 8/2) oolitic to very finely crystalline limestone and dolomite.

Devonian rocks

Rocks of Middle to Late Devonian age unconformably overlie Silurian rocks where they are present and Ordovician rocks elsewhere. The Souris River Formation, which has a maximum thickness of about 120 feet in northwestern Eddy County and averages 110 feet thick, is thinner in eastern Eddy and Foster Counties near its erosional limit just east of the county lines. It consists of light brownish-gray (5Y 6/1) to pinkish and yellowish shades of gray, shaly to argillaceous dolomite and limestone.

Systems	Rock Units	Thickness in Feet	Dominant Lithology
Tertiary	Pleistocene	0-500	Glacial drift
Cretaceous	Pierre Formation Niobrara Formation Carlile Formation Greenhorn Formation Belle Fourche Formation Mowry Formation Newcastle Sandstone Skull Creek Formation Lakota-Fall River Formations	250-1100 160-200 240-300 50-80 250-300 40-50 0-70 110-130 200-300	Shale Shale Shale Shale Shale Shale Sandstone Shale Sandstone
Jurassic	(unnamed interval) Piper Formation "Redbeds"	0-50 60-70 30-60	Shale Limestone Siltstone
Mississippian	Madison Formation Tilston interval Bottineau interval	 0-50 0-550	 Limestone Limestone & Dolomite
Devonian	Duperow Formation Souris River Formation	50-250 0-120	Limestone Limestone & Dolomite
Silurian	Interlake Formation	0-80	Dolomite
Ordovician	Stonewall Formation	0-70	Dolomite
	Stony Mountain Formation Red River Formation Winnipeg Formation	120-140 540-590 90-220	Dolomite Limestone Shale
Cambrian	Deadwood Formation	40-80	Sandstone & Dolomite
Precambrian			

Figure 5. Stratigraphic column of Eddy and Foster Counties.

The Duperow Formation, which conformably overlies the Souris River Formation, is of Late Devonian age. The thickness ranges from about 50 feet at the southeastern corner of Foster County to about 250 feet at the northeastern corner of Eddy County. The Duperow Formation is composed of grayish-orange pink (5YR 7/2), very pale orange (10YR 8/2) and pale reddish-brown (10R 5/4) cherty to chalky porous limestone and dolomite.

Mississippian rocks

Rocks of early Mississippian age unconformably overlie Devonian rocks in Eddy and Foster Counties. The Bottineau and Tilston intervals of the Madison Group are recognized in the area. The Bottineau interval, essentially equivalent to the Lodgepole Formation, has been shown by Ballard (1963, p. 19) to include a significant shale facies in its basal part. He designated this the Carrington Shale facies because of its occurrence in a well near Carrington, North Dakota. It is as much as 60 feet thick in western Foster County but thins northward and eastward. It is a pale reddish-brown (10R 5/4) bentonitic, calcareous shale. That part of the Bottineau interval above the Carrington Shale facies is as much as 500 feet thick in northwestern Eddy County, but it thins eastward to its erosional limit at the eastern boundaries of Eddy and Foster Counties. It consists chiefly of yellowish-gray (5Y 8/1) to pinkish-gray (5YR 8/1) finely crystalline to granular, cherty, argillaceous limestones and dolomites. The presence of clay commonly imparts reddish hues to the rocks.

The Tilston interval, which conformably overlies the Bottineau interval in the western part of the area, is commonly less than 50 feet thick. It consists of pinkish-gray (5YR 8/1) oolitic to powdery and chalky limestone.

Mesozoic

Jurassic rocks

Jurassic rocks unconformably overlie the Mississippian rocks in much of the area; Pennsylvanian, Permian and Triassic rocks, if they ever were deposited, have been eroded away. Redbeds above the Mississippian carbonates have previously been thought to be of Triassic age, but it is more likely that they are Jurassic. Jurassic rocks occur in approximately the western half of the area. They are from 30 to 60 feet thick and consist chiefly of moderate reddish-brown (10R 4/6) sandy siltstones and shales. These redbeds are overlain by pinkish-gray (5YR 8/1) coarse-grained to oolitic limestone. The thickness of this limestone, the Piper Formation, averages between 60 and 70 feet. It is overlain by an unnamed sequence of shales and carbonates of variable thickness at the top of the Jurassic.

Cretaceous rocks

Cretaceous rocks have been classified into three major subdivisions: the Dakota Group, the Colorado Group, and the Montana Group. All of these are represented in Eddy and Foster Counties. Formations within each group can generally be picked from lithologic studies, but they are more easily picked on electric logs.

The oldest group, the Dakota, includes the Lakota, Fall River, Skull Creek, Newcastle ("Muddy"), and Mowry Formations. Of these, the last four have been recognized in Eddy and Foster Counties. The Lakota-Fall River interval unconformably overlies rocks of Jurassic age and consists essentially of medium dark gray (N4) shale and siltstone with lenses of clean quartz sand and abundant pellets of iron carbonate. The thickness is from 200 to 300 feet, generally greater eastward toward the source. Conformably overlying the Fall River is a sequence of dark gray (N3) fissile to flaky, slightly calcareous shales. This shale constitutes the Skull Creek Formation which averages about 120 feet thick throughout the area. It is conformably overlain by the Newcastle Formation, a sequence of sandstones and siltstones generally of light grayish hues and with calcareous zones. It is from 0 to 70 feet in thickness, thickest in the southeast. The Mowry Formation, a medium dark gray shale, conformably overlies the Newcastle Formation and averages about 45 feet thick over the area.

Overlying the Dakota is the Colorado Group which includes the Belle Fourche, Greenhorn, Carlile, and Niobrara Formations. Contacts between these formations are most easily picked from electric logs although certain distinguishing lithologic features are usually evident in the samples. The Belle Fourche Formation consists of medium dark gray (N4) flaky to crumbly, calcareous, bentonitic shale which is slightly lighter in color toward the base. It averages between 240 and 300 feet thick over the area. The Greenhorn Formation consists of dark gray, soft calcareous shale which contains abundant white specks, *Inoceramus* fragments throughout, the *Globigerina* fossils near the base. The interval from the top of the Belle Fourche to the top of the Greenhorn is from 50 to 80 feet thick in Eddy and Foster Counties. The Carlile Formation consists of medium gray, noncalcareous shale. It averages from 240 to 300 feet thick. The Niobrara Formation, which conformably overlies the Carlile, consists of 160 to 200 feet of medium light gray (N6) to light brownish-gray (5YR 6/1) highly calcareous massive to fissile and compact shale. Abundant white calcareous specks are common in the upper limits of the Niobrara.

The Montana Group is represented in Foster and Eddy Counties by the Pierre Formation which conformably overlies the Niobrara Formation. The Pierre is the youngest bedrock formation in the area and lies directly beneath the glacial drift. Its thickness, variable because of the preglacial topography on its eroded upper surface, increases southwestward from about 250 feet in eastern Foster County to as much as 1100 feet beneath Hawk's Nest across Foster County

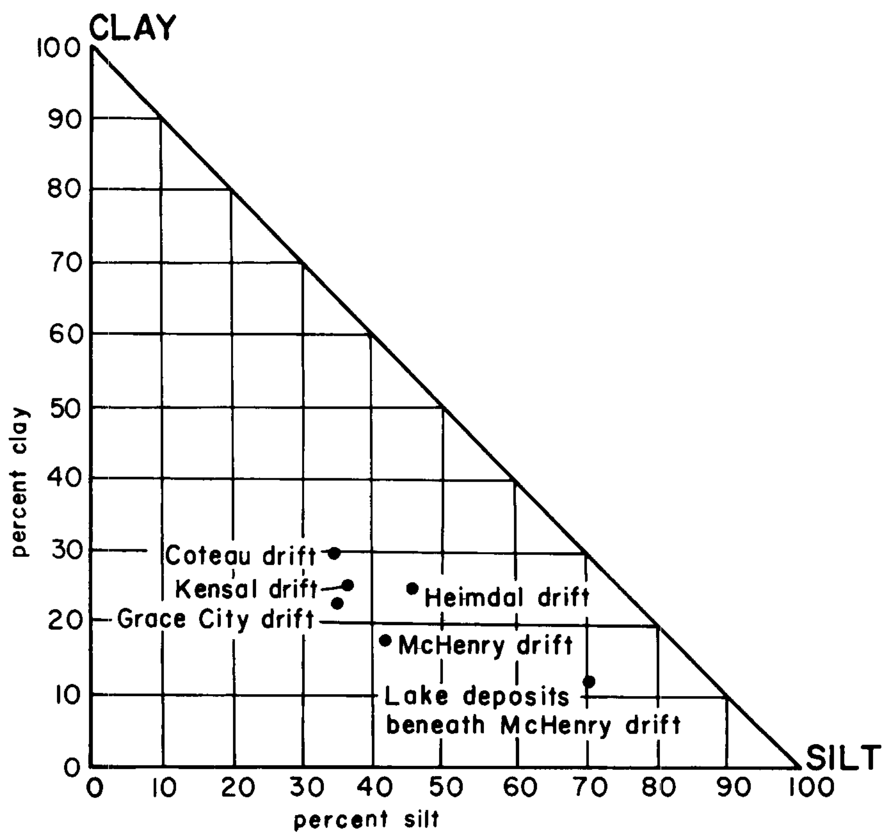

Figure 6. Graph showing average sand-silt-clay ratios in each major drift deposit of Eddy and Foster Counties. Sand percentage, the dependent variable, is the difference between the sum of the clay plus silt percentage and 100%.

line in Wells County. Unweathered, the Pierre consists of medium gray, massive to fissile, noncalcareous shales and siltstones.

The Pierre Formation crops out in about 30 localities in Eddy and Foster Counties. Two of these are in the valley of the James River and most of the rest are in the Sheyenne River Valley. Except on the shore of Warsing Reservoir near the town of Sheyenne, all exposures are highly weathered. 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.

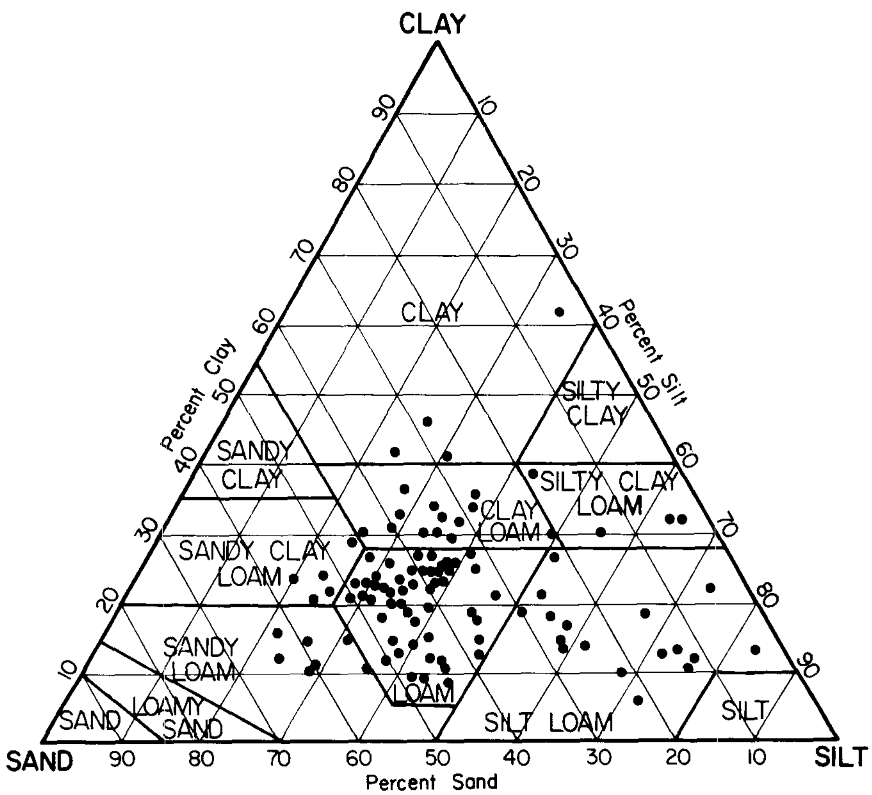

Figure 7. Sediment classification on texture diagram. Triangular coordinate graph showing size composition of till samples in Eddy and Foster Counties.

PLEISTOCENE STRATIGRAPHY

Analysis of the Surficial Drift

ANALYSIS OF TILL GRAIN SIZE

Samples of till were taken from 94 selected localities throughout Eddy and Foster Counties at depths ranging between 1 and 10 feet beneath the surface. The percentages of sand, silt and clay were determined for each 50 gram 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), said included material between 63 and 840 microns, silt included material between 4 and 63 microns and clay included everything smaller than 4 microns in diameter. Table 2 (in pocket) lists the locations of the samples along with the landforms from which they were collected and the percentages of sand, silt and clay in each sample. The average sand-silt-clay ratios for each drift are shown in Figure 6. Figure 7 shows all the till samples plotted on the standard soil classification texture diagram.

There is a wide divergence in size ratios and the tills tend to be quite sandy. Clay constitutes less than 50 percent of each sample except one and averages no more than 30 percent in any of the drifts. In Stutsman County, samples taken from end moraine and ground moraine tend to be more clayey and less variable. Samples from the Kensal drift in Foster County correspond closely in composition to samples from the same drift in Stutsman County (Winters, 1963). Samples from the Grace City drift of Eddy and Foster Counties and Wells (Kresl, 1964) and Stutsman Counties have similar sand-silt-clay ratios.

The buried lake deposits of southeastern Eddy County were also size-analyzed. These deposits contain much silt, a 70 percent average for ten samples, and small amounts of sand and clay. Although the sand and clay amounts were quite variable, the silt percentage was consistently high (table 2, part V).

ANALYSIS OF BOULDERS ON THE SURFACE

Table 3 (in pocket) shows the percentage of igneous, metamorphic and carbonate boulders recognized at the surface at 39 sites in Foster and Eddy Counties. Igneous rocks include common granite and diorite; metamorphic rocks include those with gneissic and schistose textures as well as basic types; carbonates include limestone and dolomite. Boulders of sandstone, chert and shale are so rare they are not included. Results are presented according to the drifts on which the boulders occur. Most of the studies were made on end moraine.

The percentage of igneous rocks on the Grace City and Heimdal drifts is higher than on the other three drifts, and the percentage of carbonates is corresponding low. These two drift sheets were deposited from the northwest, probably by different phases of the same ice lobe. Metamorphics reach their highest total percentages on the Kensal and McHenry drifts, both of which were deposited from an easterly direction.

ANALYSIS OF PEBBLES IN THE TILL

Table 4 (in pocket) shows the percentages of the three most common types of pebbles in till throughout Eddy and Foster Counties. Samples collected at 56 locations are grouped according to the drifts from which they were taken. An effort was made to obtain a representative number of samples and the sample sites are evenly distributed over the area.

The pebbles are grouped, in table 4, into igneous plus metamorphic pebbles, carbonate pebbles, and local bedrock pebbles. Carbonate pebbles include limestone and dolomite as well as chert which was probably derived from Paleozoic carbonate formations. Local bedrock includes shale and sandstone.

The Kensal drift contains a much higher percentage of shale pebbles than any other drift with the possible exception of the drift on the Coteau where only two samples were collected. The reason for incrased shale amounts in the Kensal drift is unclear.

Carbonates are far more abundant in the pebble size than in the boulder size. This may reflect a greater resistance on the part of the crystalline rocks to mechanical disintegration as opposed to carbonates and other sedimentary types. Shale is practically non-existent in the boulder size, but it constitutes a high percentage of the pebbles studied.

ANALYSIS OF TILL FABRIC

The orientation of pebbles in cuts in till was studied at 25 locations. Both the direction and plunge of the long axis of the pebbles were recorded. Pebbles used were restricted to those with a long (c) axis at least twice as long as the short (a and b) axes. Pebbles were removed from the till, a toothpick was carefully inserted into the hole, and a Brunton compass was used to determine the direction and plunge of the toothpick. Care was exercised in selection of the sites for the studies to minimize the possibility of the till having been influenced by either fluvial or frost action, but it was impossible to eliminate influences local bedrock topography may have had. The lack of suffiently deep surface cuts in ground moraine areas made it necessary to locate most of the sites in end moraine.

Rose diagrams drawn on a map of the area illustrate the orientation of the pebbles at each location (pl. 5). To construct these diagrams, the long axis directions of the pebbles were tabulated into ten-degree groupings and direction lines were drawn around a common axis, the length of each line representing the percentage of pebbles recorded for that direction. The long axes of the pebbles at some of the sites tend to parallel the direction from which they were deposited, but at many of the sites the pebble orientations are random.

OXIDATION AND LEACHING

Studies of the depth and degree of oxidation and leaching are sometimes helpful in differentiating drift sheets, but they were inconclusive in Eddy and Foster Counties. Factors which influence oxidation and leaching include permeability of the deposits, amount of pdecipitation, amount of erosion in progress, and the depth to the water table. Biologic activity also canges the character of the surface deposits to some extent.

Slight color variations were apparent in the till due to differences in the degree of oxidation with depth. At no place was unoxidized till found overlying oxidized till. The thickness of the oxidized zone varies but probably averages 20 to 30 feet. Most till samples taken from the surface to 4 feet deep have colors ranging from dusky to yellowish and grayish shades of brown.

Leaching is generally less than one foot deep except in some gravelly and porous areas in outwash where leaching is slightly deeper.

Bedrock Topography

The topography on the surface of the Pierre Shale in Eddy and Foster Counties, based on test hole information, is shown on plate 2.

Generally, the preglacial surface was a gently rolling plain with smooth slopes on the soft, easily eroded shale. The plain has an average elevation of 1450 to 1500 feet except on the southwest near the Missouri Coteau where it is about 1900 feet. Drainage was mainly southeastward through several broad valleys which probably were not more than 100 to 150 feet deep.

The present bedrock surface has been altered considerably from its preglacial aspect primarily by glacial meltwater which cut deep trenches, both in already existing valleys and across highs. It is sometimes difficult to differentiate between valleys of glacial origin and those that were present before the advent of glaciation, but gnerally those of glacial origin have no tributaries and are comparatively narrow. It is not unusual for meltwater trenches to intersect preglacial drainage, either above, below, or at an accordant elevation. Where such a situation exists, the preglacial valley must have been filled with drift before the meltwater trench formed.

Valleys in the bedrock are important because of the aquifers they commonly contain. The deep southeast-trending Heimdal channel which roughly bisects the area (pl. 2) was a preglacial valley that was deepened by glacial meltwater and then filled with drift, part of which forms the Heimdal aquifer, one of the best sources of water in Eddy and Foster Counties. The Carrington aquifer in northwestern Foster County, another valuable source of good water, lies on a broad bench and was apparently formed when ice that stood along the northeast edge of the bench deposited a sheet of outwash sand and gravel.

A deep south-trending valley located along the eastern edge of the two counties may connect with the Spiritwood channel to the southeast in Barnes and Griggs Counties. It seems likely this valley also existed prior to glaciation and was only modified by meltwater. A southeast-trending valley in northeastern Eddy County may have contributed to ponding of proglacial meltwater or entrapment of ice which was later covered by drift and subsequently stagnated. It generally lies beneath the area of the collapsed-outwash topography and McHenry end moraine.

A 300-to 400-foot deep northeast-trending bedrock valley in northwestern Eddy County is shown on plate 2. It may be slightly mislocated but available evidence, which includes the lowest bedrock elevation reached in Eddy and Foster Counties during the test drilling (North Dakota State Water Conservation Commission Test Hole

No. 2284), supports the interpretation shown. The valley may have carried early meltwater northeastward to the Devils Lake area. When the route was blocked by advancing ice, the water may have been diverted into the present Heimdal channel. Subsurface data in Wells County indicates that the meltwater left the valley about two miles west of the Eddy County line and flowed southeastward from there. Additional drilling is needed in the area to determine the exact course of the valley.

Glacial Phases and Associated Landforms

All the landforms of Eddy and Foster Counties are the result of glacial activity; they were all 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 east-central North Dakota these lobes had probably lost their identities. The Leeds and Souris lobes developed from the receding James lobe when the Turtle Mountains changed the flow direction of the thinner ice that was no longer able to override them.

It is possible to construct a sequential history of ice recession over Eddy and Foster Counties and adjacent areas. For purposes of discussion, it is convenient to single out ice phases that occurred while the glacier margin was receding through Foster and Eddy Counties.

In general, each of the glacial phases discussed here is characterized by an end moraine with associated ground moraine and outwash plains. Developed on these major landforms are smaller features such as eskers, kames, disintegration ridges and washboard moraines.

BUCHANAN PHASE

History

Although landforms associated with the Buchanan phase of ice activity occur only in Stutsman County, the history of the Eddy-Foster County area is more easily understood after a brief review of the history of the Buchanan phase. The Wisconsinan ice front during the Buchanan phase maintained the position shown in figure 8 for a sufficient time to deposit the Buchanan end moraine. Active ice was probably absent on the Coteau by that time and only stagnant ice remained there. The Eldridge moraine was transected by meltwater

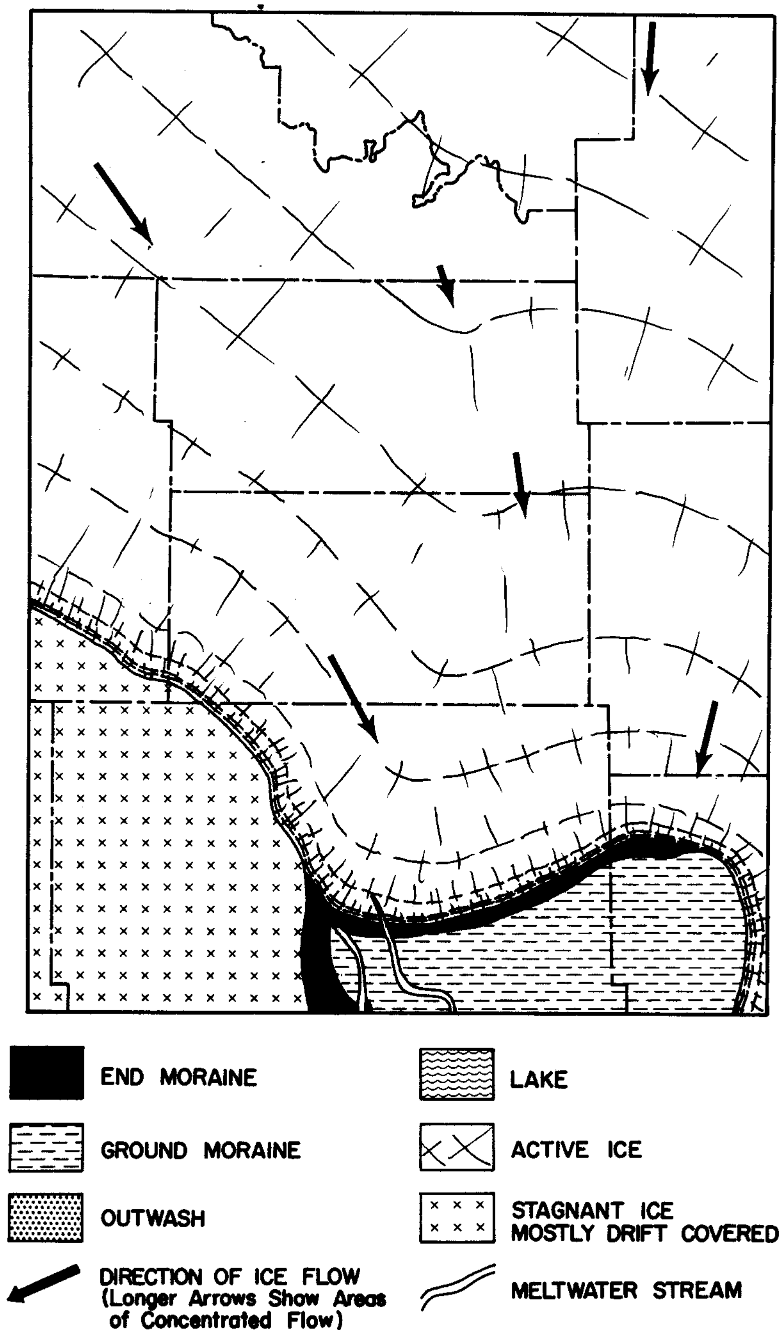

Figure 8. Buchanan phase. Formation of the Buchanan end moraine.

drainage about that time and the Pipestem Creek (lower James River system) was initiated.

As the glacier continued to melt back, the mainstream of ice flow apparently shifted eastward so that some westward lateral movement began in Barnes County as the eastern (Des Moines) lobe spread out in response to removal of the western restricting ice mass. As the mainstream of ice flow continued to shift, more rapid separation occurred between the two lobes (James and Des Moines), resulting in rapid arrival at the conditions shown in figure 10.

GRACE CITY PHASE

History

Withdrawal of the Buchanan ice front to a position essentially north-south through eastern Eddy and Foster Counties and along

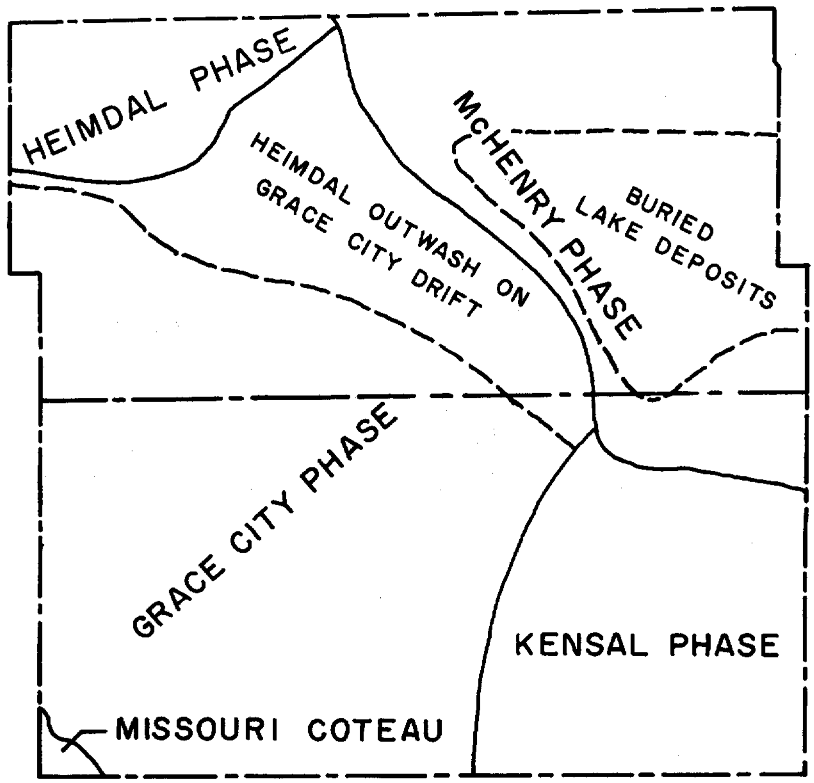

Figure 9. Map of Eddy and Foster Counties showing the areas directly affected by each glacial phase.

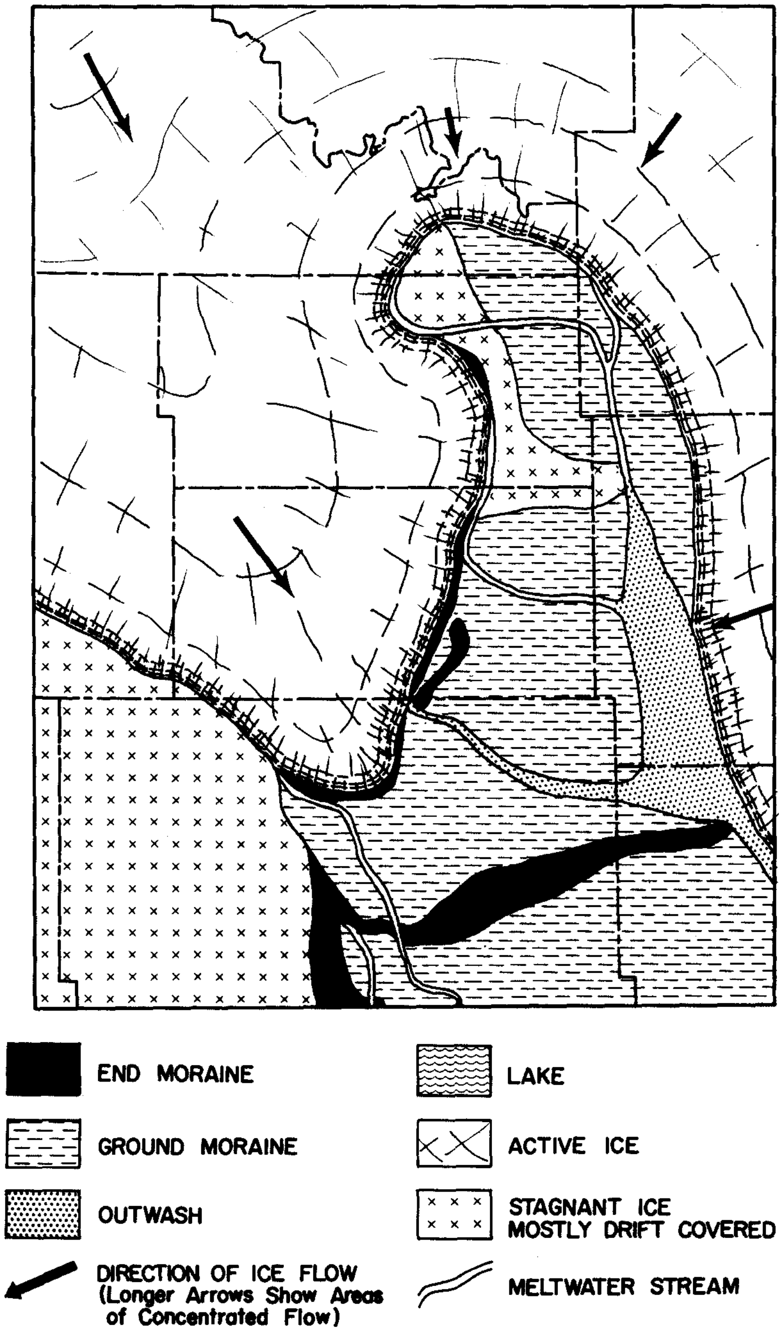

Figure 10. Grace City phase. Formation of the Grace City end moraine.

the Stutsman County segment of the Grace City end moraine resulted in a band of stagnant Grace City ice in eastern Eddy County. This stagnant ice may have been debris-covered and it probably stood quite high; it may have been more extensive than shown in figure 10. Ice advanced westward in the south toward Stutsman County while it continued to waste along the Coteau.

The extent of the Buchanan end moraine is obscure but topographic lineations suggest it extended east as far as is shown in figure 10. The small segment of end moraine shown in southern Foster County is the result of a slightly earlier stand of the Grace City ice; it is now covered by Kensal drift.

Drainage in Stutsman County at that time was largely into Pipestem Creek (Winters, 1963). In Foster County the drainage was eastward for a short distance into Griggs County where it was deflected southward by the Kensal ice front. Its southerly course after deflection is unknown. In eastern Eddy County a trench was begun for what eventually was to be the Sheyenne River. This channel was the major drainage in eastern Eddy County. The meltwater stream that formed this channel had cut through the stagnant Grace City ice mentioned above and the trench may have been quite deep. Later, this trench was kept from being completely filled by drift when an advance part of the McHenry ice moved into it from the east.

Grace City drift

Drift of the Grace City phase covers most of the western two-thirds of Foster County, the southwestern part of Eddy County and parts of Stutsman and Wells Counties (fig. 9). It occurs sporadically in central Eddy County where it protrudes through the Heimdal outwash in places. The name "Grace City" was first applied to the Grace City end moraine by Lemke and Colton (1958, fig. 5) but it has never been used as a formal stratigraphic term. The Grace City drift consists of the till of the Grace City end moraine and other associated drift that was deposited by the Grace City ice. It is named for the town of Grace City in north-central Foster County.

The McHenry end moraine in secs. 28, 29, 32, and 33, T. 148 N., R. 63 W., overlaps the Grace City ground moraine and is therefore younger. In one location (sec. 35, T. 150 N., R. 66 W.) the Heimdal end moraine truncates older washboard moraines of the Grace City drift.

Fossil freshwater snail and mussel shells and ostracode carapaces occur in several deposits of lake sediment and outwash within Grace

City drift. However, the only sample that is definitely Wisconsinan in age occurs in a deposit of medium-grained washed sand about 4 feet beneath the abandoned floor of Dry Lake near the center of sec. 18, T. 145 N., R. 64 W., 4 1/2 miles southeast of Bordulac. At that site were found *Valvata tricarinata, Gyraulus parvus,* and *Helisoma trivolvis.*

Only one radiocarbon date (W-1369) has been reported from the area but, because sampling procedures were inadequate, this date should not be accepted as valid. 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. Other landforms include end moraine, disintegration ridges, eskers, kames, lake plains, washboard moraines, meltwater channels, and terraces along the major streams. Drainage is generally poor, but better than over much of the remainder of the two counties. The entire area south of the Continental Divide drains into the James River; that part of the area north of the Continental Divide drains into the Sheyenne River.

Glacial landforms

Ground moraine — Ground moraine is defined as 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 10 feet in a square mile. The surface is pitted by innumerable nearly circular depressions averaging a few hundred feet wide. The highest elevations are at the base of the Missouri Coteau at about 1650 feet; the lowest near the James River at about 1500 feet.

The lithology of the ground moraine is mostly sandy to silty till with the sand percentages in the till tending to be higher near the outwash areas. Moderate numbers of cobbles and boulders occur on the surface; their frequency tends to increase eastward although they are abundant near Rocky Run in southwestern Eddy County. The depth to bedrock is from less than 40 feet northwest of Carrington and southwest of Barlow to about 400 feet 3 miles southwest of Grace City. It averages between 125 and 150 feet thick.

Strong northwest-southeast linearity leaves no doubt about the southeasterly advance of the Grace City ice. A kettle chain trends northwest to southeast through the center of T. 147 N., R. 67 W. and washboard moraines, abundant in areas of ground moraine, indicate that the ice margin receded to the northwest. Washboard moraines with an overall relief of about 10 feet between alternating crests and troughs are particularly abundant on the patch of ground moraine near Brantford and Grace City (pl. 1). The presence of sand and sandy till on the outer (southeast) edges of the ridges suggests that they are recessional rather than shear features.

End moraine — End moraine is defined as a ridge-like accumulation 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 its origin, may be on a small scale such as alignment of depressions, hills, or ridges, or it may be on an overall scale.

The Grace City end moraine occurs from about 3 miles northeast of Grace City southward along the west side of the James River into Stutsman County. It is between 1 and 10 miles wide in Foster County, but the main high frontal ridge averages about 1 1/2 miles across. More subdued segments of the end moraine blend westward into ground moraine; the boundary is drawn where relief ceases to average over 20 feet per square mile. Relief attains a maximum of almost 200 feet in a square mile in the Melby Hills (secs. 19, 20 and 29, T. 147 N., R. 64 W.) and at some locations along the James River. Relief of the end moraine ranges between 50 and 100 feet in a mile.

The overall north-south configuration of the Grace City end moraine and the linear features developed on the surface indicate that ice stood along an essentially north-south front while deposition was in progress. The end moraine located between the James River and Kelly Creek north of State Highway 7 has unusually large marsh-filled depressions and is probably a recessional feature. The presence of high relief east of the James River suggests that Grace City end moraine there may have been overridden by Kensal ice.

Drift of the Grace City end moraine is only a few feet thick along the James River at the Pierre Shale outcrops and more than 300 feet thick about two miles south of Grace City. Thin deposits along the James River in central Foster County are the result of the bedrock high there (pl. 2). Surface elevations appear to be virtually independent of the bedrock.

The Grace City end moraine is composed chiefly of till that is sandy in valleys with shaly, gravelly patches near the James River. Boulders and cobbles are not nearly so abundant on the Grace City end moraine as they are on the Kensal end moraine directly across the river.

Eskers and disintegration ridges — Numerous eskers and disintegration ridges occur in areas of Grace City drift. Eskers tend to be sinuous, several miles long but commonly discontinuous, and they sometimes follow pre-existing 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 longest continuous ridge in the two counties, an esker, extends southeastward from sec. 13, T. 145 N., R. 67 W. to south of the Stutsman County line (pl. 1). Although it is about 30 to 40 feet high, its location in a narrow valley keeps it from being conspicuous except from the edge of the valley. Its top is flat, up to 50 yards wide and till-covered. Two small borrow pits on its flanks expose very coarse, poorly sorted gravel. Two test holes on the esker in sec. 32, T. 145 N., R. 66 W. and sec. 13, T. 145 N., R. 67 W. penetrated about 10 feet of till before entering gravel and then penetrated about 75 feet of sand and gravel. The remaining 75 feet in both holes were silt and sand with bedrock at 148 and 157 feet, respectively (pl. 6, cross-section F-F', mile 8). The two sections are uncommonly similar and both holes produced water. The valley in which the esker lies can be traced northwestward to within a half mile of Pipestem Creek. Smaller ridge segments lie in the valley but most of the remaining ridges associated with the esker complex are not confined to valleys and are much smaller.

In sec. 21, T. 145 N., R. 67 W. a southeasterly trending ridge, extensively mined for gravel, may be an esker. Minor features interpreted as eskers occur in sec. 30, T. 147 N., R. 67 W. and in sec. 36, T. 145 N., R. 65 W. A series of small northwest-southeast trending boulder covered ridges occur in secs. 15, 16, 22, and 23, T. 146 N., R. 66 W. Another 3/4 mile long boulder-covered till ridge, which may be a disintegration ridge, occurs in secs. 6 and 7, T. 147 N., R. 66 W. 1/4 mile east of Barlow. Two large east-west trending disintegration ridges are located in secs. 25 and 26, T. 150 N., R. 66 W., and secs. 30, 20, 21 and 22, T. 150 N., R. 65 W. (fig. 11). These may actually be segments of a single ridge buried in the center by outwash and, if so, its total length would be about 5 miles. The ridges are about 30 feet high with irregular, very bouldery crests and a maximum width of about 3/8 mile. Roadcuts and a small gravel pit located on the south edge of the ridge in sec. 21 exposed limited amounts of sand and gravel. The disintegration ridges probably were deposited near the Grace City ice margin during its final breakup.

In secs. 23 and 24, T. 150 N., R. 65 W., just east of the ridge described above, is a group of high hills and small ridges composed almost entirely of sand and gravel. These hills, which are as high as 70 to 80 feet above the surrounding outwash plain, bear a superficial resemblence to kames but some of them are elongated and lack the conical shape typical of kames. They are apparently kames that were smeared out by renewed ice movement. The general northwest-southeast orientation of the ridges is parallel to the inferred direction of ice movement in the area. The hills may have formed in stagnant ice left by the wasting Grace City glacier if the stagnant ice extended that far west. If the area was covered by stagnant ice, lows in the ice might have been filled with outwash.

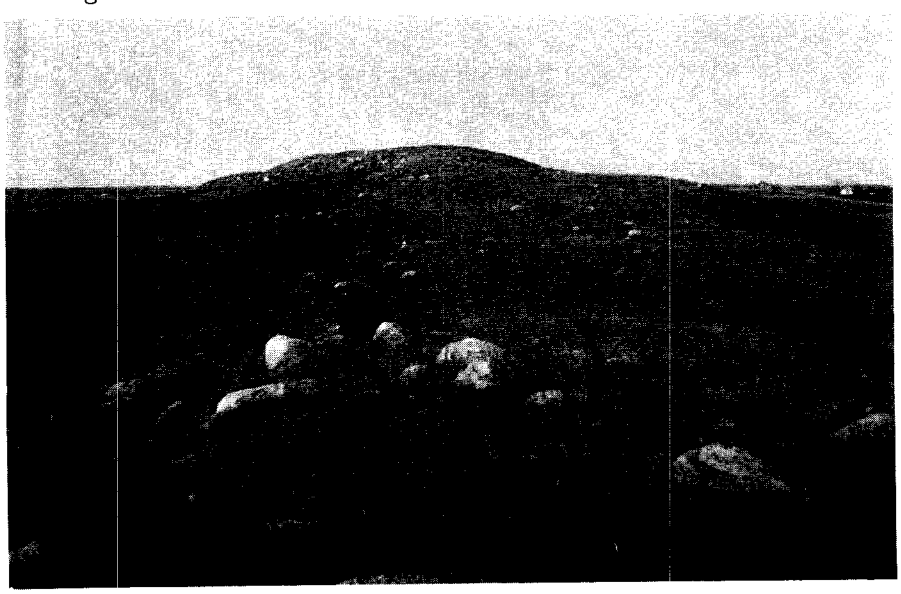

Figure 11. Disintegration ridge. Sec. 25, T. 150 N., R. 66 W. Crest of ridge is very bouldery and the sides are steep. View is to the east.

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 Eddy and Foster Counties fit this definition well.

Only one prominent kame occurs on the Grace City moraine of Eddy and Foster Counties. It is located in sec. 3, T. 145 N., R. 64 W., in the Grace City end moraine and is a prominent landform, visible, because of its elevation (1650′), for several miles. The kame was originally about 1/8 mile across at the base and 60 feet high but about half of it has been mined for gravel and sand.

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 body of outwash. Coarse gravel is most common in the outwash of Eddy and Foster Counties but fine sand and boulder sized gravel also occur.

A small outwash plain borders both sides of Kelly Creek in northwestern Foster County. It is about 7 miles long and up to 5 miles wide with a total area of about 20 square miles. Relief is commonly about 3 feet in a square mile. Channel and meander scars, none of which continue for any appreciable distance, are common. The outwash plain has a southeasterly regional slope, parallel to Kelly Creek. The lithology of the outwash is predominently sand, the texture of which is medium to coarse and gravelly in places. Its average thickness is unknown, but in a few locations near the edge of the plain, it is less than 4 feet thick and underlain by till. The thickness is probably not great anywhere. Surface elevations are almost identical to those on the Eddy County outwash plain and the two outwash bodies are interconnected by a complex channel system. However, much of the outwash in Foster County may have been derived from the west in Wells County.

Another smaller outwash plain is in secs. 6, 7, 8, 16, and 18, T. 145 N., R. 67 W. on either side of Little Pipestem Creek adjacent to the northern edge of the Missouri Coteau. Relief is about 5 feet in a mile laterally but the plain slopes southeastward at about 10 feet in a mile. The lithology is mostly clean sand and gravel. Boulders are absent from the surface. This outwash was probably derived largely from melting stagnant ice on top of the Coteau although some may have come from the northwest.

Meltwater channels — Water flowed from the margin of the melting glacier through meltwater channels. Meltwater channels which cross the area include those now occupied by Pipestem Creek, Rocky Run, Scotts Slough, and Kelly Creek. The James River also occupies a large meltwater channel which will be discussed later in this report.

The channel of Pipestem Creek is from 25 to 40 feet deep with well-defined banks which have suffered little post-glacial modification. About 1/10 mile wide at the Wells County line, it widens to 1/2 mile below its confluence with Little Pipestem Creek. A few small terraces occur along Pipestem Creek in Foster County. Recent silty alluvial material lines the floor of the meltwater channel to an unknown depth.

Scotts Slough, the overall shape of which suggests an ice marginal channel, is a narrow, gravel-lined meltwater channel averaging between 20 and 25 feet deep. Gravel beneath the channel floor has yielded considerable water, and springs are common at the edges. The channel extends about 5 miles west into Wells County in ground moraine. It was probably cut by meltwater from the receding Grace City ice, perhaps while that ice still bounded it on the north. A small valley in secs. 1, 12, and 13, T. 147 N., R. 66 W. northeast of the juncture of Scotts Slough with Kelly Creek appears to have been a continuation of Scotts Slough before it was cut off by Kelly Creek.

Rocky Run, which crosses the extreme northwestern corner of Foster County and flows northeastward through southwestern Eddy County to the James River, occupies a meltwater channel that spreads out about three miles north of Barlow into an outwash plain. One mile west of the county line it is about 1/8 mile wide and 25 feet deep; in Eddy and Foster Counties it is nowhere over 10 feet deep. The channel is floored by very abundant cobbles and boulders and contains sand and gravel. Gravel pits are located in the channel in secs. 25 and 26, T. 148 N., R. 67 W. The channel begins in Wells County, and it may be a part of the same system that produced Pipestem Creek and Scotts Slough.

Kelly Creek flows southeastward through the outwash plain previously discussed and continues from the plain through a deep meltwater channel in the Grace City end moraine. The channel begins approximately where the creek crosses State Highway 7 and becomes progressively narrower and deeper downstream. At the highway it is about 10 feet deep, 3 miles downstream it is about 30 feet deep, and in the end moraine it is up to 70 feet deep and as narrow as 1/10 mile across at the base. Such a deep and restricted channel must have been formed when ice was nearby, and it probably predates the outwash plain further northwest along the creek. The channel was later used by the water which deposited the outwash.

Another short meltwater channel extends southeastward from Dry Lake through one of the highest patches of Grace City end moraine in southern Foster County (secs. 20, 29, and 32, T. 145 N., R. 64 W.). This channel, about 100 feet deep where it breaches the high segment of end moraine, apparently drained Dry Lake and Lake George, both of which were more extensive during late Wisconsinan time. This channel too was cut while ice was nearby because many easier routes could have been utilized by the water if ice had not directed it. To the northwest, Dry Lake and Lake George lie in an extension of the valley which can be traced to a point about two miles northeast of Carrington. A deep drift-filled bedrock valley (pl. 2) lies beneath the meltwater channel.

Lake Plains — The plain of Dry Lake in secs. 13 and 14, T. 145 N., R. 65 W. and secs. 18 and 19, T. 145 N., R. 64 W. is underlain by lake clay overlying medium to coarse sand and gravel. The lake originally formed in a meltwater channel which was dammed when because of a decreased meltwater supply the channel became partially filled with sediment. Fossil mollusk shells found in the sand beneath the plain surface have been identified by Tuthill (personal communication, 1963) as probably pre-Recent in age.

One mile northwest of this lake plain is another, slightly larger, plain associated with the intermittent Lake George. Located mostly in secs. 4 and 9, T. 145 N., R. 65 W. it also occupies a part of the former meltwater channel in which the lake plain of Dry Lake lies. In addition to the present beach, three higher beaches are recognized around Lake George but their ages are unknown. The only shells found in the lake sediments were recent (Tuthill, personal communication).

Several other small lake plains occur on the ground moraine (pl. 1). Most are underlain by thin silt and clay deposits on till and have poorly developed shore features. Brackish lakes occupy the plains during wet years. Four lake plains occur in the end moraine southwest of Grace City. They were probably formed as ice marginal lakes in a similar manner to those along the Stutsman County line in the

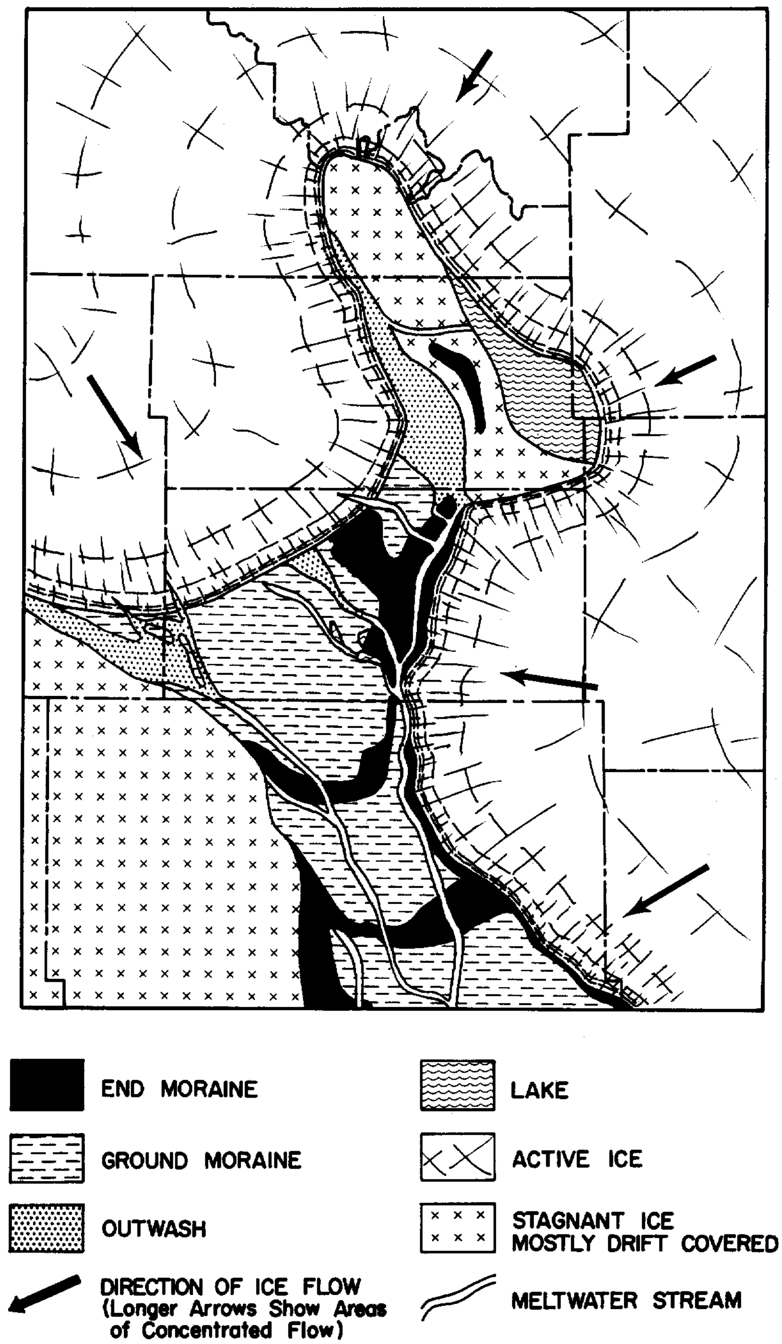

Figure 12. Kensal phase. Formation of the Kensal end moraine.

Kensal end moraine. They are underlain by brown, silty to sandy, clay. Coarseness generally increases with depth suggesting that moving water was active during early stages of the formation of the features. Pebbles, cobbles, and boulders are absent from the surfaces.

Nonglacial landforms

Lakes and sloughs — Sloughs occur throughout western Foster County in many of the abundant depressions. They sometimes are moderate-sized lakes during wet years, but normally they are little more than marshlands. The only permanent lake, Juanita Lake, is located in secs. 7, 8, 17, 18, and 19, T. 147 N., R. 63 W. It occupies a deep channel which carried meltwater from the nearby glacier.

KENSAL PHASE

History

During the Kensal phase, the Grace City ice front had withdrawn on the north as shown in figure 12. In western Foster County the Grace City ice was receding except for a temporary pause a few miles south of Carrington where a hilly area of drift was deposited. The band of stagnant Grace City ice in Eddy County remained but the southeast end of it was covered by the Kensal ice.

In Foster County, Pipestem and Little Pipestem Creeks continued to extend headward. If the active Grace City ice had thinned sufficiently to melt back a short distance from the escarpment, Little Pipestem Creek may have extended further back into Wells County along the Coteau escarpment. Little Pipestem Creek apparently carried a large volume of water from the melting Grace City ice front as well as runoff from the Coteau.

The Kensal ice during this phase reached its maximum extent and the McHenry ice in northeastern Eddy County was continuing to advance. The advance of ice along the Kensal-McHenry front trapped meltwater to form the proglacial Lake McHenry in eastern Eddy County between the extant band of stagnant ice and the active front. The former limits of the lake are not accurately known but lake sediments occur widely within the area shown as a lake on figure 12. In places, till of the McHenry drift is very silty because of incorporated lake deposits and it is nearly indistinguishable from the lake deposit, a condition that further makes recognition of the former lake boundary difficult.

During the Kensal phase, the present north-south part of the

James River was established. Advancing Kensal ice forced the meltwater into increasingly further western routes until the water eventually flowed against the Grace City end moraine in Foster County. The complex of channels in T. 145 N., R. 64 W. probably resulted when the Kensal ice advanced a short distance westward over the Grace City end moraine and established the westernmost channel; the ice front then slowly receded, and each successive channel to the east was cut as the higher, more western one was abandoned in favor of a lower route. The Kensal end moraine became the new eastern bank for the James River.

Drainage in Eddy County was southward between the active Grace City ice front and the stagnant ice band. It is possible that the glacial Lake McHenry overflowed the stagnant ice in places and contributed to this southward-flowing meltwater. All the meltwater was carried by the new James River in Foster County.

Kensal drift

Drift of the Kensal phase covers the eastern third of Foster County, the northeastern part of Stutsman County and parts of Griggs and Barnes Counties (fig. 9). The name "Kensal" was first applied to the Kensal end moraine by Lemke and Colton (1958, fig. 5) but it has never been used as a formal stratigraphic term. Winters (1963, p. 61) discussed the Kensal moraine and associated landforms in Stutsman County. The Kensal drift consists of the till of the Kensal end moraine and other associated drift that was deposited by the Kensal ice. It is named for the town of Kensal, two miles south of the Foster County line in Stutsman County.

Inferred geologic history is the main basis for distinguishing the Kensal drift from other drifts. The McHenry end moraine overlaps the Kensal drift truncating older washboard moraines and is therefore younger. The James River separates the Kensal and Grace City drifts. The two drifts are about the same age and correspond to Lemke and Colton's second advance (1958, p. 55, fig. 5). Positional and topographic relationships in secs. 1, 12, and 13 of T. 146 N., R. 64 W. indicate that the Kensal drift locally overlies the Grace City drift. The lithologies of the two drifts do not differ enough to distinguish any stratigraphic unconformity.

Landforms of the area include end moraine, ground moraine, disintegration ridges, eskers, lake plains and washboard moraines. Drainage is eastward to the Sheyenne River in the ground moraine. Drainage is interior in the end moraine except in certain areas along the James River where it is westward. Bald Hill Creek heads at Stoney Lake and flows eastward through a large meltwater channel which widens into an outwash plain at the Griggs County line.

Glacial landforms

Ground moraine — The ground moraine of the area associated with the Kensal phase is poorly drained and has many shallow, marsh-filled depressions. It was not possible to distinguish lodgement till from ablation till although widespread areas of washed till and lenses of sand suggest abundant ablation till. Exposures along State Highway 20 south of Glenfield reveal lenses of sand within a more conventional clay-till, and many small hills have till tops and cores of sand and gravel. Sand is more abundant to the north indicaing that the Bald Hill meltwater stream may have spread over the adjacent areas depositing discontinuous areas of outwash before it established its channel. The surface of the ground moraine is covered with abundant boulders and cobbles.

The depth to bedrock is 40 feet about 3 miles north of Glenfield and more than 300 feet about 5 miles west of Glenfield but it averages between 125 and 150 feet. The variation is due mainly to irregularities in the bedrock surface.

Washboard moraines, straight to arcuate, low, linear ridges of drift, chiefly till, are abundant in the ground moraine area. Some washboard moraines may have formed as seasonal accumulations at the margin of the melting ice and may be annual features. Others probably formed when material beneath the glacier was brought to the surface of the ice along shear planes in the ice. Regardless of the mechanism that formed them, washboard moraines apparently formed parallel to the margin of the glacier and are useful for determining the direction of retreat of the ice margin. Washboard moraines in the area of the Kensal phase indicate the ice margin receded southeastward.

End moraine — The Kensal end moraine occurs from about 2 miles north of Juanita to south of the Stutsman County line (pl. 1) and southeastward into Barnes County. It is from less than 1 to more than 7 miles wide in Foster County but it merges with the ground moraine behind it to such an extent that no sharp boundaries can be designated. Both large- and small-scale linearity are apparent on the Kensal end moraine. Local relief averages between 20 and 40 feet in a square mile, considerably more than on the ground moraine to the east. A transitional zone of relatively lower relief, subdued end moraine, extends about 7 miles north from the Stutsman County line along the inner (eastern) margin of the end moraine. Boulders and cobbles that cap the end moraine are abundant, especially on ridges near the James River.

The depth to bedrock beneath the Kensal end moraine is generally greater than 200 feet with the thinnest deposits on the outer (western) margin along the James River. This is the result of a bedrock high along the James River (pl. 2). An area of relief over 70 feet in a square mile in secs. 1, 12, and 13 of T. 146 N., R. 64 W. is unusually high for the Kensal end moraine. It is more characteristic of the Grace City end moraine west of the James River and suggests that Kensal ice advanced over pre-existing end moraine of the Grace City lobe. Plate 6, cross-section D-D′ between miles 25 and 38, shows this relationship.

The till of the Kensal end moraine is mainly silty and clayey, that is, loam and clay loam. Sand and gravel occur in a few places along the Stutsman County line. In the end moraine in southern Foster County, high ridges enclose lake beds which existed at the margin of the receding ice. Lake silts and clays are common in these areas (pl. 1) but they are everywhere thin and restricted.

Gravel ridges — Ridges of gravel which may be eskers or disintegration ridges were mapped as gravel ridges. The only gravel ridges that occur in the area are in sec. 7, T. 145 N., R. 62 W. They end at a shallow channel suggesting that they formed at the ice margin and the water that deposited them, on leaving the ice, carved the channel. Because the channel leads to a lake plain, the lake must have existed while ice was present nearby.

Linear till disintegration ridges — Several low, linear till disintegration ridges were mapped near Glenfield. They intersect at nearly right angles, suggesting that a regular joint pattern existed in the disintegrating ice. The preferred orientations of most of the ridges is northwest-southeast and northeast-southwest, parallel and transverse, respectively, to the inferred direction of overall ice movement in the area. They are very low, difficult to see in the field, but easily seen on aerial photographs and topographic maps.

Proglacial landforms

Meltwater channel — The only major meltwater channel in the area associated with the Kensal phase is the one now occupied by

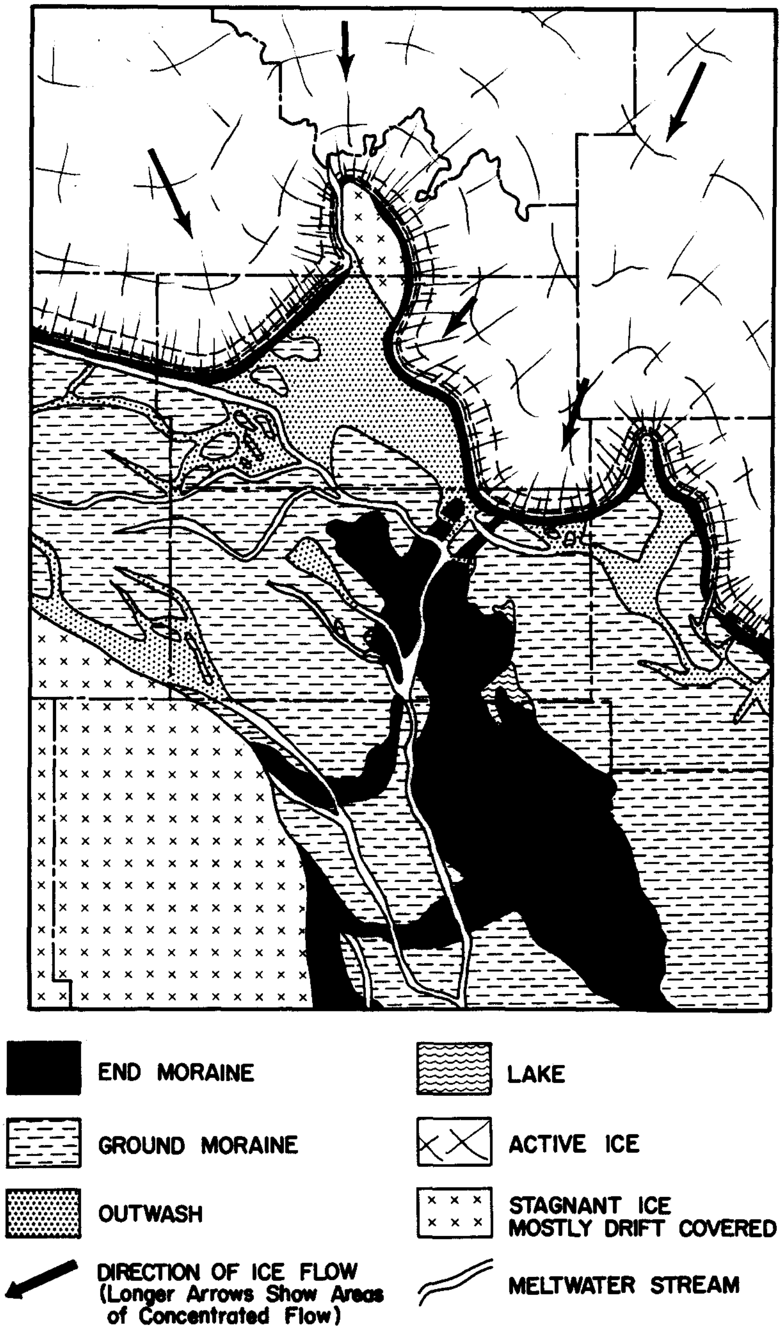

Figure 13. McHenry-Heimdal-Cooperstown phase. Formation of the McHenry, Heimdal and Cooperstown end moraines.

Bald Hill Creek (pl. 1). It occurs from near Juanita Lake southeastward to about 3 miles east of Juanita and from there eastward into Griggs County. Generally about a mile wide except at the county line where it widens into an outwash plain about 3 miles wide, the channel is from 30 to 50 feet deep with a terrace system developed about one-third of the way up from the present base. The channel contains discontinuous minor meltwater deposits of sand and gravel as well as recent alluvial materials. It carried meltwater from McHenry ice and perhaps from the more distant Heimdal ice of northwestern Eddy County.

McHENRY-HEIMDAL-COOPERSTOWN PHASE

History

The drifts of the Heimdal and McHenry end moraines apparently were deposited simultaneously, and to the southeast the till of the Cooperstown end moraine may have been deposited about the same time. The Kensal ice was wasting while the Heimdal and McHenry ice fronts stood at their maximum positions. As the Kensal front receded, lakes formed at the margin near the Foster-Stutsman County line.

As the glacier wasted from its Grace City to its Heimdal position, a broad sheet of outwash was deposited in central Eddy County (fig. 13). The major watercourse that was last to develop was the one that is now occupied by the James River in Eddy County. Bald Hill Creek meltwater channel carried water from the McHenry ice eastward through northeastern Foster County during this phase, but some of the water may have flowed southward through the James channel.

Heimdal drift

The drift of the Heimdal phase is exposed over the northwestern corner of Eddy County, the northern part of Wells County and the southern and western parts of Benson County. The name "Heimdal" was first applied to the Heimdal end moraine by Branch (1947, p. 6) but it has never been used as a formal stratigraphic term. The Heimdal drift consists of till of the Heimdal end moraine and other associated drift that was deposited from the Heimdal ice. It is named for the town of Heimdal in northern Wells County. It corresponds to part of Lemke and Colton's third advance (1958, p. 58).

Inferred geologic history is the main basis for distinguishing the

Heimdal drift from other drifts. Its relationships to the Grace City drift have already been discussed. Relationships with the McHenry drift are obscure but in Benson County the two end moraines join at Sully's Hill on the south shore of Devils Lake and they are separated south of there by an outwash plain 2 to 3 miles wide. The Heimdal and McHenry drifts were probably deposited at about the same time.

Landforms in this area include end moraine, ground moraine, outwash plains, disintegration ridges, and a large meltwater channel with associated terrace levels. The terraces are not treated in detail here; all the terraces of the Sheyenne and James Rivers will be discussed in a separate chapter.

Glacial landforms of the Heimdal phase

Ground moraine — The small areas of ground moraine located north of the Heimdal end moraine have an average relief of less than 20 feet in a square mile but some hills rise as high as 50 feet above surrounding areas. Drainage is good near the Sheyenne River which separates the ground moraine into small patches. The topography is characterized by rounded hills separated by valleys which lead to the Sheyenne River and to the outwash plains. Slopes are generally smooth and gentle within the ground moraine but they steepen near the end moraine and outwash plains. The few depressions that occur are small and shallow in contrast to the abundant and deep depressions found in the ground moraine associated with the Grace City phase to the south. Washboard moraines indicate that the ice margin receded in a northwesterly direction.

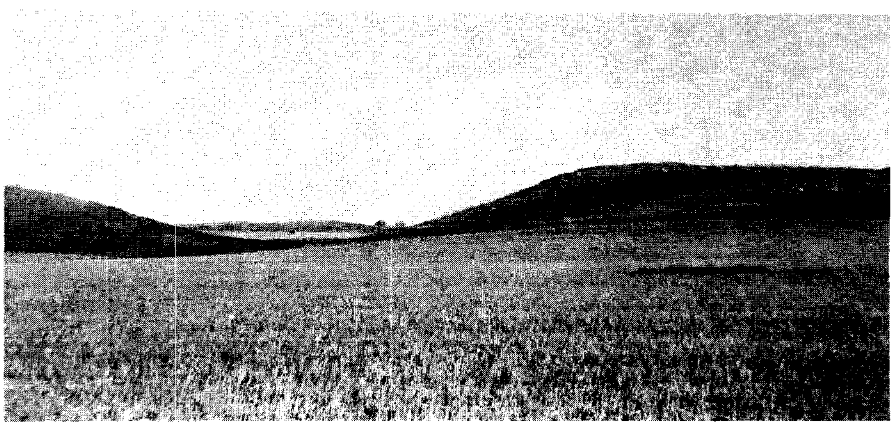

Figure 14. Disintegration ridge. Sec. 31, T. 150 N., R. 66 W. with a gap where a stream was superimposed. View is to the northwest.

The lithology of the till of the ground moraine is mostly sandy to silty. Sand on the surface was probably deposited by meltwater before definite outwash plains were developed. The depth to bedrock beneath the ground moraine averages between 50 and 100 feet thick except near the Sheyenne River where it is generally less than 50 feet thick. Boulders and cobbles are numerous on the surface.

End moraine — The Heimdal end moraine of northwestern Eddy County is essentially a V-shaped wedge, the apex of which points southeastward (pl. 1). It is a well-defined 3 to 6 mile wide strip of hills which continues westward into Wells County and northward into Benson County. The topography in the Heimdal end moraine is quite variable ranging from closely spaced ridges as in sec. 7, T. 150 N., R. 65 W., to broad, flat sags as in secs. 31 and 32, T. 150 N., R. 67 W. Local relief on the end moraine averages between 50 and 100 feet in a square mile but is as much as 150 feet in a square mile. Flat areas up to 1/2 square mile are common. Some large depressions occur sporadically. High ridges of the end moraine, most of which trend northeast-southwest tend to be grouped into close-knit bodies. Boulders and cobbles are abundant on the Heimdal end moraine.

The drift of the Heimdal end moraine consists mostly of clayey, silty till, but restricted areas of sand, probably the result of local washing, are common. Some roadcuts such as the one bordering the north and east sides of sec. 10, T. 149 N., R. 67 W., expose very dense lodgement till which is overlain by looser, lighter ablation till. In Eddy County the depth to bedrock beneath the Heimdal end moraine averages between 100 and 150 feet except in the southwest on the Wells County line where it is as much as 200 feet and in the northeast near the Sheyenne River where it is as little as 50 feet.

Disintegration ridges — Disintegration ridges are located in secs. 31 and 32 of T. 150 N., R. 66 W. and secs. 3 and 4 of T. 149 N., R. 66 W. One (fig. 14) is about 3/4 mile long and as much as 45 feet high. Near its west end it is breached by a channel that was cut when a stream was superimposed on the then subglacial ridge. The ridge is boulder-covered and composed chiefly of gravelly till with a few inclusions of stratified sand.

Another disintegration ridge is about 1 1/4 miles long and 40 feet high, and it too is breached by a meltwater channel. Boulders are abundant on the surface of the ridge. Gravel and clean sand occur in sufficient quantity to warrant mining.

Proglacial landforms of the Heimdal phase

Outwash plains — Outwash plains associated with the Heimdal advance are located on either side of the Sheyenne River on the inner margin of the Heimdal end moraine and ahead of the end moraine over a wide area of central Eddy County (pl. 1).

The outwash plains north of the end moraine, now separated by the large channel of the river, are shown by regional relationships to have been continuous at one time. The slope on these outwash plains is southeastward. Except for some very flat areas, about 10 feet of local relief is common on the plains which are from 10 to 50 feet lower than the surface of the surrounding ground moraine. Their surfaces are covered by sand and gravel of varying quality; it has not been utilized because of the availability of higher quality gravel along the Sheyenne River northwest of Sheyenne. Extensive test hole data are lacking but several holes in the vicinity of Sheyenne indicate that the outwash is not more than 10 or 15 feet thick. Boulders lie on the surface too, not in abundance, but in numbers greater than is common on other outwash in the area.

The largest outwash plain in the two counties is located in front of the Heimdal and McHenry end moraines and generally north of the James River although several extensions occur south and west of the river. The outwash covers about 160 square miles, slightly more if the associated outwash south of the James River is included. Relief is generally 2 or 3 feet in a square mile with some depressions and ridges due to recent wind erosion. The regional slope is predominently southeastward away from the Heimdal end moraine with the lowest elevations about two miles northeast of Grace City where the meltwater was funneled through a gap in the Grace City end moraine.

The lithology is mostly medium to coarse sand and gravel overlain in places by a foot or less of clay. The surface is also commonly veneered by buff colored, light, loose silty to sandy loess as much as 4 feet thick, which is especially common in Tps. 149 and 150 N., R. 65 W. It is unevenly distributed and commonly has a till-like appearance but pebbles are invariably absent.

Till is present beneath the outwash at depths less than 5 feet; several isolated areas of ground moraine protrude through the outwash surface. Test holes in the outwash penetrated between 5 and 20 feet of sand and gravel indicating that the thickness is probably not great anywhere. The topography of the area immediately prior to deposition of the outwash is unknown but it probably was similar to the ground moraine surface of the Grace City phase of western Foster County. If this is so, the outwash has simply filled the minor lows and graded the surface to a plane. Even those areas of ground moraine that were not buried beneath the outwash are thoroughly washed and have numerous small sand-filled valleys.

Except for the low elevations northeast of Grace City, some of the lowest elevations on the outwash are located along the front of the McHenry end moraine. This low band marks an early route of the Sheyenne River before it became entrenched in its present channel. Most of the outwash was derived from meltwater of the Heimdal phase but some of it may have come from other glacial stands to the west in Wells County.

McHenry drift

The drift of the McHenry phase is exposed over the eastern third of Eddy County, the northeastern corner of Foster County, northwestern Griggs County, southwestern Nelson County and southeastern Benson County. It consists of till of the McHenry end moraine and other associated drift that was deposited from the McHenry ice

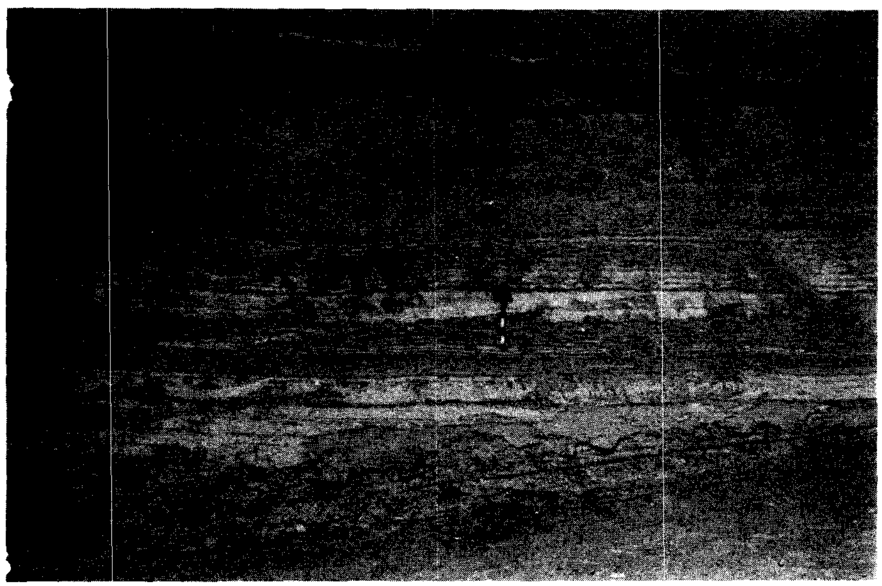

Figure 15. Fresh excavation in southwestern Nelson County. This cut about six miles southwest of Tolna exposes a deposit of proglacial McHenry lake sediments. Silt is underlain by dense, clayey till and overlain by looser, silty till.

and corresponds to part of Lemke and Colton's third advance (1958, p. 58). It includes an extensive area of buried lake sediments in eastern Eddy County (figs. 15 and 16.) The McHenry drift is named for the town of McHenry in northeastern Foster County.

Although freshwater snail and mussel shells were collected at several locations within the McHenry drift, only two of the fossil assemblages appear to be of Pleistocene age. These are as follows:

1. A marly lake deposit located in a meltwater channel in the SE 1/4 sec. 9, T. 149 N., R. 62 W. At this site were found the pelecypod *Pisidium* and the aquatic gastropods *Valvata tricarinata, Valvata Lewisi, Lymnaea humilis,* and *Gyraulus parvus.*
2. A well-bedded and banded lake deposit located in a topographic low in collapsed outwash, NW 1/4 NW 1/4 sec. 34, T. 150 N., R. 64 W. At this site were found all the species listed at the above site as well as the aquatic gastropods *Armiger crista, Helisoma anceps,* and *Helisoma* sp.

Closely associated with and underlying the McHenry drift is a sequence of lake deposits in eastern Eddy County and western Nelson

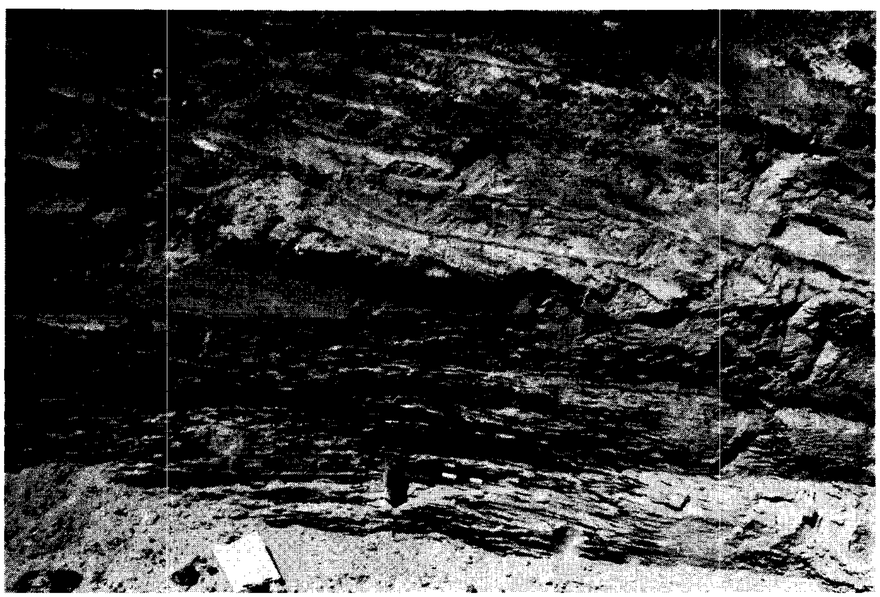

Figure 16. Fresh excavation in eastern Eddy County. This cut is about eight miles north of McHenry. The lower part of an eight foot till deposit is shown overlying a sandy shore facies deposit of the proglacial McHenry lake.

County (fig. 9). Neither its lateral extent nor its thickness are accurately known. It was deposited in a proglacial lake between the advancing McHenry glacier and the band of stagnant Grace City ice in east-central Eddy County. With continued advance of the McHenry glacier, the lake sediments were overridden and largely covered by till (figs. 15 and 16).

The lake deposits average about 70 percent silt with the remainder equally divided between sand and clay. No pebbles or cobbles are present in the drift. Rhythmic banding is common but no aquatic fossils were found.

Landforms in the area include end moraine, collapsed end moraine, ground moraine, outwash plains, disintegration ridges, eskers, meltwater channels, drumlins, washboard moraines, kames, lake plains and sand dunes. Much of the drainage is interior. Lakes are abundant and at least five of them, Johnson Lake, Horseshoe Lake, Lake Coe, North Washington Lake and South Washington Lake possess some degree of permanency. Others are temporary and become alkali flats during dry weather.

Glacial landforms of the McHenry phase

Ground moraine — The largest area of ground moraine in northeastern Eddy County is located in Tps. 148 and 149 N., R. 62 W. Relief averages about 20 feet in a square mile except near the numerous meltwater channels where it is much greater. Slopes are relatively low and smooth but they steepen abruptly near the end moraine. Depressions are uncommon on the ground moraine; boulders and cobbles are abundant.

Sandy to silty till is the most common lithology in the ground moraine. In some places near meltwater channels, 1 to 2 feet of sand overlies the till indicating that the meltwater spread over parts of the ground moraine before it cut distinct channels. The depth to bedrock beneath the ground moraine is from about 100 feet on the west to more than 300 feet at the Nelson County line over a buried channel which trends north-south near the county line. It is locally thin in the area of the drumlins. Washboard moraines, particularly those of T. 149 N., R. 62 W. trend east-west in an arc-like configuration with the concave side northeastward indicating north to northeasterly recession of the glacial margin. Although they are not noticeable on the ground, the washboard moraines show up well on aerial photographs.

End moraine and collapsed end moraine — The end moraine which extends northwestward from northeastern Foster County to north of the Benson County line is named the McHenry end moraine (pl. 1). It is very patchy, collapsed in many places, and broken into segments which are separated by ground moraine, lakes, lake plains and outwash.

Relief is as much as 300 feet in a mile but averages between 50 and 100 feet. Elevations are lowest in the collapsed areas but the surface is particularly rough there; a relief of 60 feet in a square mile is typical. The southwesternmost, outer ridge is well-defined and is from 1/2 to 2 miles wide. Northeast of this ridge the end moraine is more patchy and poorly defined. The average width is about 6 miles.

The McHenry end moraine was deposited by an ice lobe that advanced from the northeast over a band of stagnant Grace City ice. The stagnant ice was confined chiefly to a bedrock valley and formed a long band that later melted, causing collapse of the overlying end moraine and associated features. The outermost ridge of the end moraine, deposited southwest of the stagnant ice, and the inner part, deposited northeast of it, did not collapse; it is in these areas that the highest elevations, up to 1764 feet above sea level, occur.

Lithologies are variable; in the uncollapsed areas sandy, silty till is common; in collapsed areas shaly sand, gravel and intermixed till are typical. The gravel is coarse, composed of up to 90 percent shale, and is worthless for most economic purposes. Boulders and cobbles are numerous on the uncollapsed parts of the end moraine but uncommon in the collapsed areas.

It is sometimes difficult to determine whether an area is underlain by outwash or till because the lithologies are mixed. In a cut along the southwest side of sec. 2, T. 150 N., R. 64 W., till is found overlying coarse, shaly gravel. It is loose, particularly at its contact with the gravel. This relationship, and others like it, illustrates the unstable environment that prevailed while the stagnant ice was melting. Much shifting and sliding of materials occurred when the underlying ice melted away (fig. 17). In places, till forms the surface of topographic lows. In such areas stagnant ice was particularly thick, so no outwash was deposited on it. In some of the outwash areas (secs. 5, 7 and 8, T. 150 N., R. 64 W.) collapse was minor and the area is considered to be pitted outwash plain.

The thickness of the drift beneath the McHenry end moraine varies from about 50 feet along the southwest edge to about 200 feet on the inner (northeast) side except locally on the Griggs County line where it is 300 feet over a buried channel (pl. 2). The stagnant ice on which the drift was deposited probably averaged between 20 and 60 feet thick; this is indicated by the magnitude of collapse.

Drumlins — Drumlins, narrow, linear, streamlined ridges of varying length, width and height and composed of till, stratified drift and bedrock, occur along the inner margin of the McHenry end moraine and on the ground moraine behind it. They were first recognized by Colton and Lemke (1955) and later discussed by Aronow (1959). Aronow mapped nearly 160 "linear features" in a 144 square mile area which includes approximately equal amounts of Eddy and Benson Counties in Tps. 150 and 151 N. and Rs. 62, 63 and 64 W. In addition to those drumlins mapped by Aronow, several more were mapped during the present project in T. 149 N., Rs. 62 and 63 W. Some of these in T. 149 N., R. 62 W. on ground moraine are as much as 2 miles long and are similar to those mapped near Velva, North Dakota by Lemke (1958). Although they are not noticeable in the

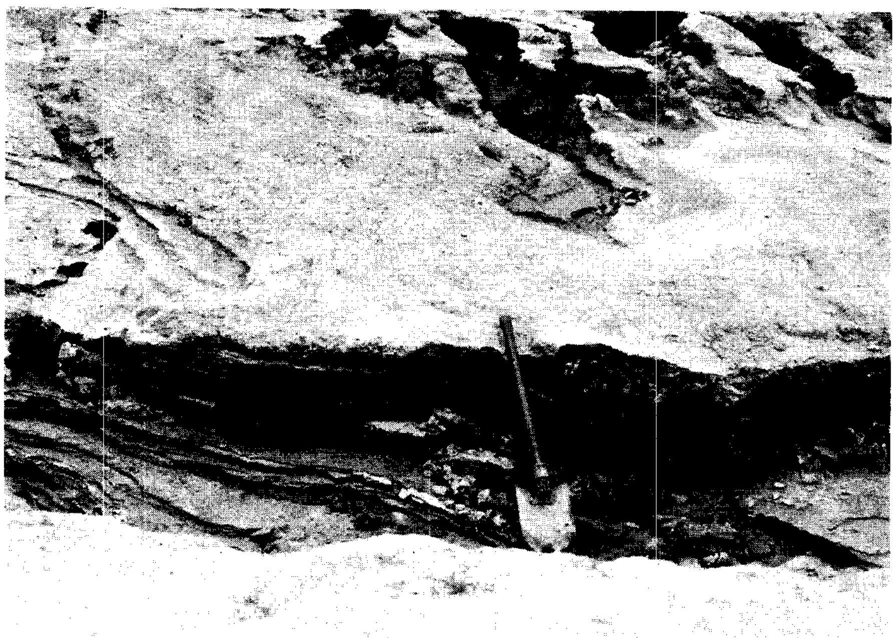

Figure 17. Ice-contact sand deposit. Sec. 12, T. 148 N., R. 63 W. Slumping is typical of the collapsed part of the McHenry end moraine and adjacent collapsed outwash.

field, these long drumlins are easily identified on aerial photographs. The shorter ridges are as much as 30 feet high, in contrast to the longer ones, which are less than 5 feet high. The drumlins fan out in such a way that those in the southeast, which trend NNE-SSW, and those in the northwest, which trend ENE-WSW, could be extended inward to a common axis (pl. 1); this relationship illustrates the spreading nature of the glacier margin.

Several auger holes were bored in the drumlins in two locations. In the SE 1/4 of sec. 22, T. 150 N., R. 63 W., three parallel ridges which trend about 55° east of north were extensively augered. These three ridges have previously been mapped by Aronow as "drumlins or related features." A shale core was penetrated in the southernmost ridge, till in the northernmost ridge and at least 4 feet of fine to medium grained sand cored the center ridge. All three ridges were surfaced by till and boulders.

At the other location, the NW 1/4 of sec. 6, T. 150 N., R. 63 W., and extending into sec. 1 on the west, a 1/16 mile long oval-shaped ridge about 25 feet high was augered in three places. Five feet of very shaly till on top of in-place shale was penetrated in the northeast hole; 5 feet of very shaly, silty till was penetrated in the center hole; 4 feet of till, slightly less shaly than in the center hole was penetrated in the southwesternmost hole. The hill is, in part at least, a bedrock high and has the shape commonly ascribed to classical drumlins.

The presence of shale outcrops in patches of ground moraine south of Warwick and at such a shallow depth beneath the drumlins is certainly evidence enough to suggest a generally thin drift covering. The mechanism which formed the drumlins is not clear. Aronow (1959), after exploring several possible causes for drumlin formation, especially in the Warwick-Tokio area, drew no conclusions but suggested that a hypothesis incorporating an understanding of some, as yet, unknown interaction among the ice, terrain, and material was needed.

Gravenor (1953) proposed a "modified erosion theory" to explain drumlin formation. His theory entails two steps:

1) Masses of till and stratified materials would be deposited at the front of an advancing glacier if there was a temporary halt during the ice advance.
2) Ice riding over this drift would erode and shape it and thereby produce drumlins.

He further points out (Gravenor and Meneley, 1958) that clayey till, when water-saturated, is highly plastic and readily shaped. Lemke (1958) believes, with some reservations, that narrow linear ridges which contain stratified materials " . . . were formed by glacier ice advancing over stratified deposits, eroding and shaping the deposits into ridges and then plastering a layer of till over the deposits."

The drumlins of northeastern Eddy County described above generally occur along the northeast flank of a bedrock high which coincides with the inner margin of the McHenry end moraine. A proglacial lake existed between the advancing McHenry ice and the stagnant Grace City ice and when sediments of this lake and clayey till with a very high water content were overridden by the advancing ice, drumlins may have formed in a manner similar to that outlined by Gravenor and Meneley. The presence of the bedrock high and the associated stagnant ice may have influenced the type of glacial flow and served as an impetus to initiate scouring and shaping.

Eskers and disintegration ridges — Eskers and disintegration ridges are numerous in the area. Most of them are associated with the collapsed part of the end moraine but some occur in the ground moraine behind the end moraine.

In secs. 3 and 4, T. 150 N., R. 64 W., and directly to the north in Benson County in secs. 33 and 34, four sinuous ridges 1/4 to 1 1/4 miles in length occur in an area of collapsed outwash. The ridges, composed of fine, shaly gravel and sand have few surface boulders and are up to 20 feet high and about 150 feet wide. They were probably deposited by streams which flowed in cracks or valleys in the stagnant ice. Till was observed in some of the lows between the ridges but shaly outwash is more common. The presence of till suggests that the stagnant ice may have been too thick and high in some places for outwash to accumulate on it.

A ridge that occurs in secs. 22, 27, 32, 33 and 34 of T. 150 N., R. 64 W. is up to 30 feet high, 200 feet wide, almost 4 miles long, and is completely surrounded by collapsed end moraine. It is composed of medium-grained clean sand and fine gravel and has a surface that is nearly boulder-free. It terminates in end moraine above the Sheyenne River and was probably formed in a westerly-flowing stream in an open crack in stagnant ice.

Ridges such as those in secs 13 and 24 of T. 150 N., R. 64 W. are common in the collapsed end moraine. They are composed of sand and gravel of essentially the same lithology as the surrounding outwash. Commonly, one end of a ridge is flush with slightly higher areas in the outwash which may not have collapsed as much as other lower areas. The ridges apparently formed in cracks that may have been enlarged by streams flowing through the disintegrating ice. Similar features described by Flint (1928) have been called "crevasse fillings."

Features similar to those described above occur in the collapsed end moraine north and northeast of McHenry. Some of these are more than 2 miles long and up to 50 feet high. Typically, one end is in outwash of the same lithology as the ridge and in sec. 22, T. 148 N., R. 63 W. one terminates in end moraine. These ridges were formed when water issuing from the active ice flowed southward over stagnant ice though valleys it had cut in the ice. Another high ridge located on the Eddy-Foster County line in the middle of a meltwater channel in sec. 33, T. 148 N., R. 63 W., and sec. 4, T. 147 N., R. 63 W. is 60 feet high and a mile long. It is composed of sand and gravel and is boulder-covered.

Other ridges are located in the area around North and South Washington Lakes. A low sinuous ridge, slightly over a mile long and about 15 feet high trends east-west through secs. 4 and 5, T. 149 N., R. 63 W. It is composed of the same shaly gravel that surrounds it. Two sinuous ridges are located on the northeast side of North Washington Lake in secs. 27 and 34, T. 150 N., R. 63 W. and secs. 2 and 3, T. 149, R. 63 W. These also are composed of shaly sand and gravel but they stand above till of the ground moraine. The northernmost of the two ridges extends into collapsed outwash. Another discontinuous ridge located in secs. 15, 16 and 21, T. 149 N., R. 63 W. is composed of fine, clean sand, is about 10 feet high, is nearly 2 miles long, and is surrounded by shaly gravel and sand.

Located on the Nelson-Eddy County line in secs. 12 and 13, T. 149 N., R. 62 W. and secs. 18 and 19, T. 149 N., R. 61 W. are several northwest-southeast trending ridges. They are up to 70 feet high but average about 30 feet. These gravel and sand ridges, none of which is over a mile long and most of which are less than 1/4 mile long, stand on a northeast-sloping till plain. Ridges are also present 1/2 mile to the southeast on the opposite side of the meltwater channel now occupied by Johnson Lake. Until they were breached by the meltwater channel, they were continuous for a distance of about 5 miles.

Kames — Only the major kames are shown on plate 1. The largest kames in the two counties are located in secs. 13 and 14, T. 150 N., R. 64 W. (fig. 18). They are about 100 feet high; the largest is 1/4 mile across at the base, and they are surrounded by collapsed end moraine, which probably buries part of their bases.

Several small kames, the largest of which is about 60 feet high, are located in secs. 24 and 25, T. 149 N., R. 63 W. Kames southwest of McHenry in secs. 13, 14, and 23, T. 147 N., R. 63 W. are from 30 to 60 feet high, and at least one of them (NE 1/4, sec. 23, T. 147 N., R. 63 W.) has been mined for gravel.

Several small kames occur in the SW 1/4, sec. 2, T. 150 N., R. 64 W. They formed between stagnant ice and the active McHenry ice which was depositing end moraine in the area. The discontinuity of the deposits suggests that each separate knob may represent delta deposits of small streams which issued from the active ice.

Proglacial landforms of the McHenry phase

Outwash plain — North of the Sheyenne River behind the McHenry end moraine in northeastern Eddy County is an outwash plain which extends northward into Benson County and eastward into Nelson County. Except for restricted areas of ground moraine interrupting it south of Warwick it is quite continuous. Relief is generally

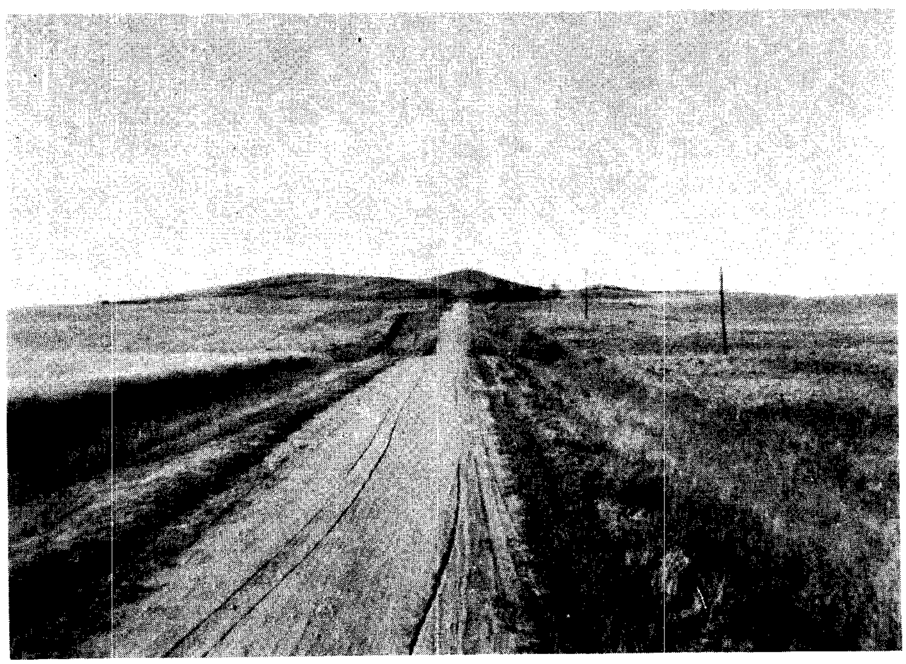

Figure 18. Kames. Secs. 13 and 14, T. 150 N., R. 64 W. These kames, the largest in Eddy and Foster Counties, are about 100 feet high and 1/4 mile across at the base. View is to north.

less than 5 feet in a mile, due primarily to recent wind erosion. The lithology is medium to coarse, clean sand with a reddish hue due to oxidized iron, probably from shale. The thickness of the sand probably averages less than 20 feet decreasing to a veneer just north of the Sheyenne River. It was deposited by meltwater from ice that formed the North Viking end moraine about 5 miles north of the Eddy County line during a later stand of the same glacier that deposited the McHenry and Heimdal end moraines.

South of the Sheyenne River outwash from the same source as that north of the river lies in an extensive network of valleys that are as much as 100 feet deep in the McHenry ground moraine and even deeper in the end moraine (pl. 1). All the water that flowed through the network of valleys was apparently funneled into the deep valley in secs. 33, 34, and 35, T. 148 N., R. 63 W. The outwash south of the Sheyenne River was deposited at the same time as that north of the river, prior to the cutting of the east-west segment of the river because, if a trench had been present, it would mark the southern limit of the outwash plain. Outwash over till is exposed in the river trench in sec. 22, T. 150 N., R. 62 W. (fig. 19).

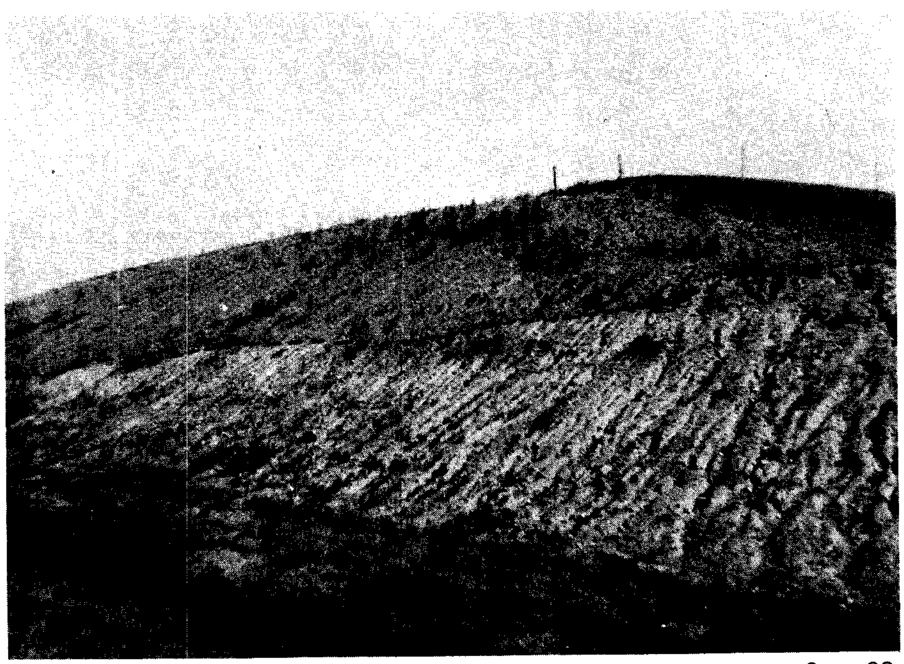

Figure 19. Outwash overlying till north of the Sheyenne River. Sec. 22, T. 150 N., R. 62 W.

Nonglacial landforms of the McHenry phase

Lakes and sloughs — Small temporary lakes are abundant in the area. Most are less than 1 square mile and quite shallow. All are saline or brackish, and when they dry up, a white alkaline crust remains. Lake plains surround some of the lakes, but mollusk shells found in these lake sediments are mostly recent forms. The most extensive of the lake plains are those south and east of McHenry.

Five lakes that retain some degree of permanency are Johnson Lake, Lake Coe, Horseshoe Lake, North Washington Lake and South Washington Lake. Marsh occurs around the edges of the lakes as well as in other lows. Most of the lake plains are composed of thin dark clays, which commonly overlie till or gravel, and many of the lake sediments contain fossiliferous marl. The surfaces are free of boulders.

Sand dunes — Groups of sand dunes have been developed north of the Sheyenne River on the outwash plain in northeastern Eddy County near Hamar. Individual dune groups range in areal extent

Figure 20. Sand dunes west of Hamar in northeastern Eddy County. The dunes lie on the outwash plain and are now stable with dense aspen stands.

from small patches to large tracts several miles long. The total area in which dunes occur is about 25 square miles.

Individual dunes consist of ridges up to 1/4 mile long with about 6 feet of relief from highs to adjacent lows. Crests generally trend northwest-southeast and the dunes consist of parallel to subparallel ridges which form northwestward trending groups. The dunes commonly coalesce, and comparatively shallow troughs separate their rounded crests. The dunes are now stable with dense stands of aspens (fig. 20). Commonly, the ridges consist of very homogeneous fine-grained sand, whereas, the intervening lows which extend into the outwash, are underlain by coarser sand and gravel.

NORTH VIKING PHASE

History

The last major pause in the recession of the glacier in the immediate area of Eddy and Foster Counties was the one that deposited the till of the North Viking end moraine (fig. 21). Later, more distant melting ice to the north and the draining glacial Lake Souris continued to influence the development of drainage in the area. To the northwest the Martin ice front was probably receding by now because the till of the North Viking end moraine overlaps the till of the Martin end moraine in Benson County.

The till of the McHenry end moraine, which had been deposited on top of the stagnant Grace City ice in eastern Eddy County, may have begun to collapse during this phase. The till of the McHenry end moraine was deposited both slightly beyond the western edge and within the eastern margin of the stagnant ice and only the center part collapsed.

In northwestern Eddy County, meltwater from the North Viking ice flowed southward to the Heimdal end moraine and was deflected northeastward by the moraine. Meltwater from the North Viking ice in southeastern Benson County flowed southward over the McHenry end moraine cutting entirely through it and forming many deep channels. All of this water apparently flowed out the gap in secs. 33, 34, 35, and 36 of T. 146 N., R. 63 W. From there it flowed down the James River or Bald Hill Creek.

COTEAU PHASE

History

Although it is not known with certainty which ice advance or advances deposited the drift on the Coteau in Foster County, much of

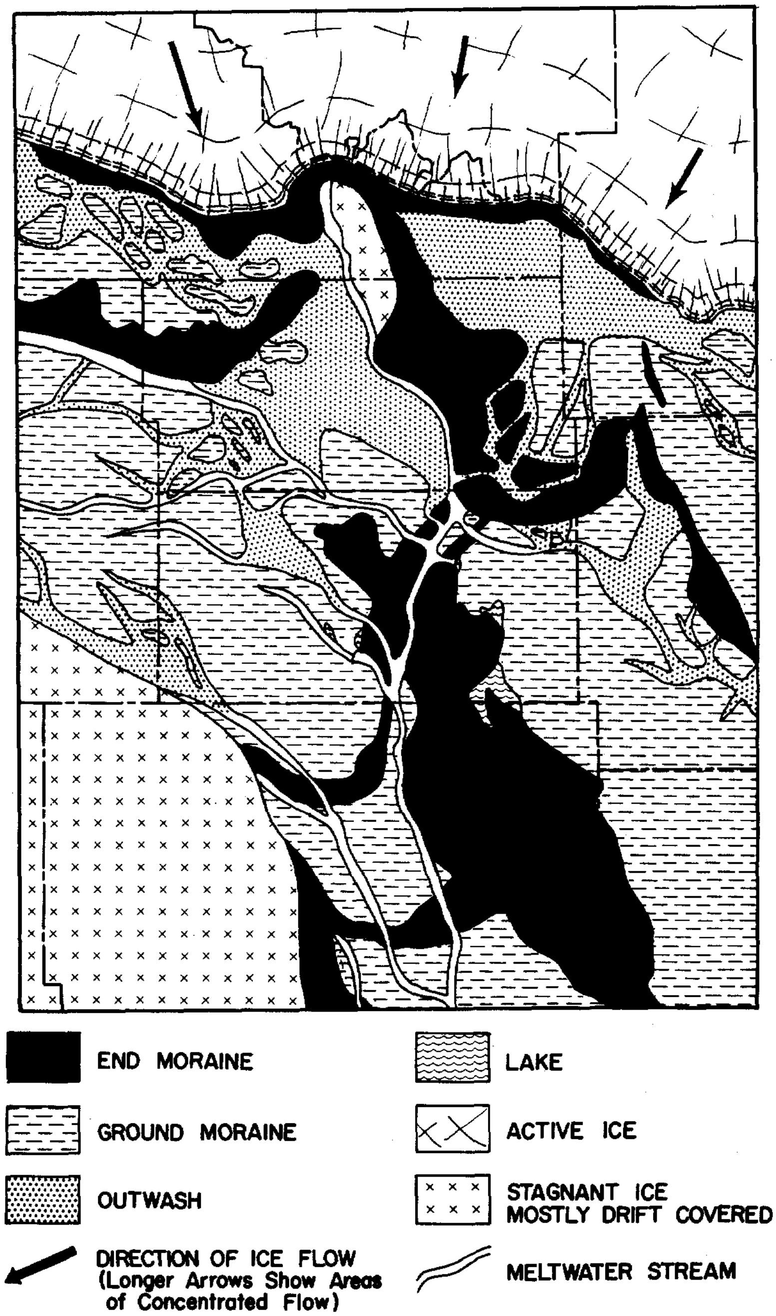

Figure 21. North Viking phase. Formation of the North Viking end moraine.

the moraine was probably deposited by a phase of the same James lobe which later deposited the Grace City and Heimdal drifts. Dead-ice moraine results when areas of stagnant ice overlain by thick drift melt, irregularly lowering the drift. Lemke and Colton (1958; with Lindvall, 1963) have suggested that the northeast face of the Coteau is a continuation of the Grace City end moraine and therefore part of the Grace City drift, but this is doubtful. Neither local nor overall linearity exists on this part of the Coteau and significant lithologic evidence to support such a possibility is also lacking. To the west in Wells County no evidence to support such a situation was found (Kresl, 1964, oral communication). In Stutsman County, Winters (1963, pl. 1) indicates that the Grace City end moraine terminates four miles south of the Foster County line.

Coteau drift and landforms

The Coteau drift occurs over about 6 square miles in the southwest corner of Foster County. It covers the Missouri Coteau, a band of dead-ice moraine that extends from northwest to southeast across

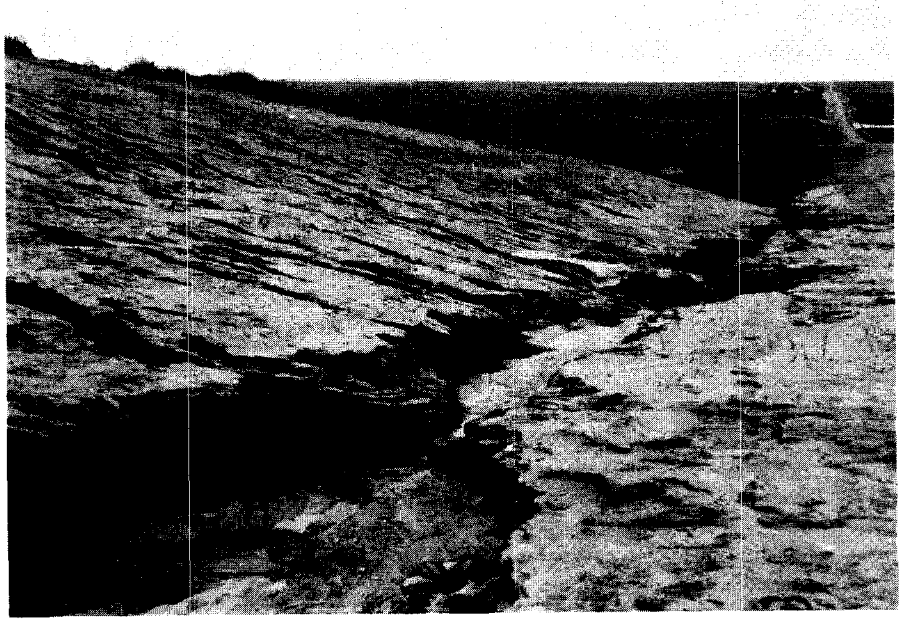

Figure 22. Ice-contact deposit at north edge of dead-ice moraine. Little Pipestem Creek valley in background. View is north along the Wells-Foster County line.

the state of North Dakota (figs. 1 and 9). The escarpment to the Coteau, and in particular the prominent, till-covered "Hawks Nest" of southeastern Wells County (secs. 25, 26, 35, and 36 T. 145 N., R. 68 W.), is a landmark visible as much as 20 miles away. The area is characterized by very hilly moraine with relief of as much as 150 feet in a mile, non-integrated drainage, numerous small irregularly-shaped lakes and sloughs, and landforms that resulted when widespread deposits of stagnant ice overlain by thick accumulations of drift melted, causing collapse. The Coteau drift occurs at elevations approximately 300 to 400 feet higher than the Grace City drift.

Till is the dominant lithologic type in the dead-ice moraine but patches of outwash occur without apparent predictability (fig. 22). Boulders and cobbles are numerous to abundant on the surface. A test well on top of "Hawks Nest" penetrated 179 feet of drift, much of it outwash. Drift thickness, probably quite irregular, is controlled in part by a bedrock high which underlies the area.

General Summary of the Glacial History

The only valid divisions of the Pleistocene Series now recognized in east-central North Dakota are the Wisconsinan and Recent Stages. Evidence has not yet been found to prove whether pre-Wisconsinan ice advanced over the area but features such as the buried Heimdal channel and the Carrington aquifer were probably formed during either pre-Wisconsinan or early Wisconsinan glaciations. It is likely that pre-Wisconsinan drift is present in east-central North Dakota. A dense and jointed till that underlies the Napoleon drift in Logan County may belong to a pre-Wisconsinan stage (Clayton, 1962, p. 55). The Napoleon drift, possibly deposited during the first advance of Wisconsinan ice over the area, has been dated as older than 38,000 years by three radiocarbon dates in Stutsman and Logan Counties.

After deposition of the Napoleon drift, the ice margin probably receded to the Missouri Coteau and conceivably remained there until about 12,000 years ago when the Long Lake and Burnstad drifts were deposited. Shortly thereafter the active ice receded northward from the Coteau, depositing the series of end moraines and associated landforms that have been discussed on the preceding pages. No reliable radiocarbon dates have yet been obtained from the drift that was deposited during this recession; until they are obtained, it will be difficult to determine when the active ice margin receded through the area.

As the late Wisconsinan glacier thinned and receded, it became increasingly affected by topographic highs over which it flowed. Thick ice that had been flowing undisturbed over the underlying bedrock highs became blocked by those highs when it had thinned substantially. This resulted in lobation as the ice was forced to flow around the highs. In east-central North Dakota, evidence for such lobation is most graphically illustrated by the irregular pattern of the end moraines.

The two major late Wisconsinan ice lobes in the area were the James and Des Moines lobes. The James lobe flowed generally southeastward between the Missouri Coteau and the Red River Valley, while the Des Moines lobe flowed generally southward through the Red River Valley. The James lobe was forced to split at least twice in east-central North Dakota as it thinned over bedrock highs.

Details of the lobation of the late Wisconsinan ice can be inferred from a study of the end moraines. The James lobe deposited the Buchanan end moraine in northern Stutsman County before the flow direction of the ice was substantially affected by the topographic highs mentioned above. Later, when the James ice thinned so that it could not override the Sully's Hill high in T. 152 N., R. 65 W. about 10 miles north of the Eddy County line, it flowed around both sides of it, leaving a band of stagnant ice on and to the south of the high in eastern Eddy County. The ice flowing around the west side of the high deposited the Grace City end moraine. The ice that flowed around the east side became indistinguishable from the Des Moines ice, and, for all practical purposes, became part of the Des Moines lobe. The Des Moines lobe then expanded westward and deposited the Kensal end moraine in the area that had been covered by James ice before it was diverted by the Sully's Hill high. The Des Moines ice trapped meltwater in eastern Eddy County to form a proglacial lake; sediments deposited in this lake were subsequently overridden as the ice readvanced westward to deposit the McHenry end moraine. The James ice, which was continuing to thin and then recede northward after diversion by Sully's Hill, finally became too thin to override the Turtle Mountains on the Canadian line. It split into the Leeds and Souris lobes. The Leeds lobe flowed south around the east side of the Turtle Mountains and deposited the Heimdal end moraine. The Souris lobe did not extend far enough east to affect Eddy and Foster Counties. Ice then receded from the two-county area. The Leeds lobe receded northward and deposited the North Viking end moraine north of Eddy County essentially parallel to the Heimdal end moraine. The Des Moines lobe receded slowly eastward and deposited the Cooperstown and Luverne end moraines before becoming confined to the Red River Valley.

Meltwater that continued to flow into Eddy and Foster Counties even after the area was free of active ice caused considerable erosion of the James and Sheyenne River valleys. The Sheyenne valley in particular was deepened during the draining of glacial Lake Souris. Terraces in the valley represent successive stages during the draining of the lake.

MAJOR RIVER VALLEYS AND TERRACES

The James and Sheyenne Rivers flow in valleys that were cut primarily by glacial meltwater. The valleys were probably initiated by meltwater from nearby ice, but later much of the meltwater may have come from more distant ice than that which covered Eddy and Foster Counties. The gravel deposits of the valleys are of economic importance.

James River Valley

The James River, which crosses Eddy and Foster Counties, originates in Wells County and flows generally southward to its mouth on the Missouri River near Yankton, South Dakota. Its trench is about 30 feet deep and 1/2 mile wide in Eddy County but as much as 100 feet deep and less than 1/10 mile wide in parts of Foster County. In central North Dakota the James River is an intermittent stream. Important tributaries to the James River include Rocky Run and Kelly Creek in Eddy and Foster Counties and Pipestem Creek which joins the river at Jamestown in Stutsman County. Another tributary valley 3 miles east of Grace City carries no stream but is occupied by Juanita Lake.

Floodplain and terraces

In addition to the present floodplain, 3 distinct terrace levels are present in the James River valley. For purposes of discussion and comparison with the Sheyenne River terraces, these terraces have been assigned names, most of which were derived from townships in which they are well developed. Wherever possible, origin of the terrace is also indicated. Plate 3 is a profile parallel to the James River showing the terraces above the river. Plate 4 shows the locations of the terraces.

The floodplain of the James River is composed of stratified sand and silt which, because of its high organic content, tends to be dark gray. One test hole drilled in sec. 21, T. 145 N., R. 64 W. in an abandoned part of the valley, penetrated silt, sand and gravel to a depth of 38 feet. Elsewhere, the thickness of the alluvium is not known. The floodplain is marked by innumerable meander scars, sloughs, cutoffs and oxbow lakes.

The lowest of the three terrace levels consists of four separate terraces which occur 10 to 30 feet above the present floodplain. The Munster terrace (A), on the Wells County line, and the Pleasant Prairie cut terrace (B) in T. 148 N., Rs. 65 and 66 W. have sporadic occurrences of gravel and sand, cross-bedded in places, on the till surface. These terraces appear to correspond to the Brantford fill terrace (C) which is underlain by at least 17 feet of gravel which has been commercially developed in sec. 4, T. 147 N., R. 65 W. The Haven cut terrace (D) occurs sporadically about 25 feet above the present floodplain south of the bend in the James River. The system of meltwater channels along the James River in T. 145 N., R. 64 W. (fig. 23) is considered to be nearly contemporaneous to the Haven cut terrace and is so designated on plate 3.

The second major terrace level is represented by only one extensive terrace, the Larabee cut terrace (E) which occurs about 30 to 40 feet above the present floodplain in secs. 1, 2, 11, 12, 14 and 23 of T. 146 N., R. 64 W. It is almost invariably surfaced by till; the few restricted gravel and sand deposits are insufficient for economic purposes. The Larabee cut terrace is veneered by a cobble pavement and is extensively scarred by shallow abandoned channels.

The highest terrace level, represented by the Bucephalia (F) and Refuge (G) cut terraces, occurs sporadically on the western slopes of the valley on the Grace City end moraine in Tps. 145 and 146 N., R. 64 W. Only scattered patches of gravel veneer the surfaces. The terraces are 45 to 60 feet above the floodplain and may have been formed by streams that were trapped between the active Kensal ice front and the Grace City end moraine.

Sheyenne River Valley

The Sheyenne River originates in Sheridan County and flows eastward across the northern half of Eddy County, then southward to Ransom County where it curves northeastward and joins the Red

River north of Fargo. In Eddy County it flows in a trench 100 to 150 feet deep and from 1/4 to 1 mile wide. The valley is deeper and narrower in areas where it passes through end moraine; shallower and wider in areas of outwash and ground moraine. In extremely dry or cold weather the Sheyenne River ceases to flow. No major tributaries enter the river in Eddy County, and drainage a short distance away from the valley is essentially non-integrated throughout much of eastern Eddy County.

Floodplain and terraces

In addition to the present floodplain, four distinct terrace levels can be recognized in the Sheyenne valley. Some of these, especially the lower levels, are only local and are not correlatable over wide areas. The higher levels occur about 100 feet above the present floodplain; the lower, at heights less than 40 feet above the floodplain. The terraces have been assigned names which were derived from townships in which they are well developed.

The floodplain of the Sheyenne River is composed of highly

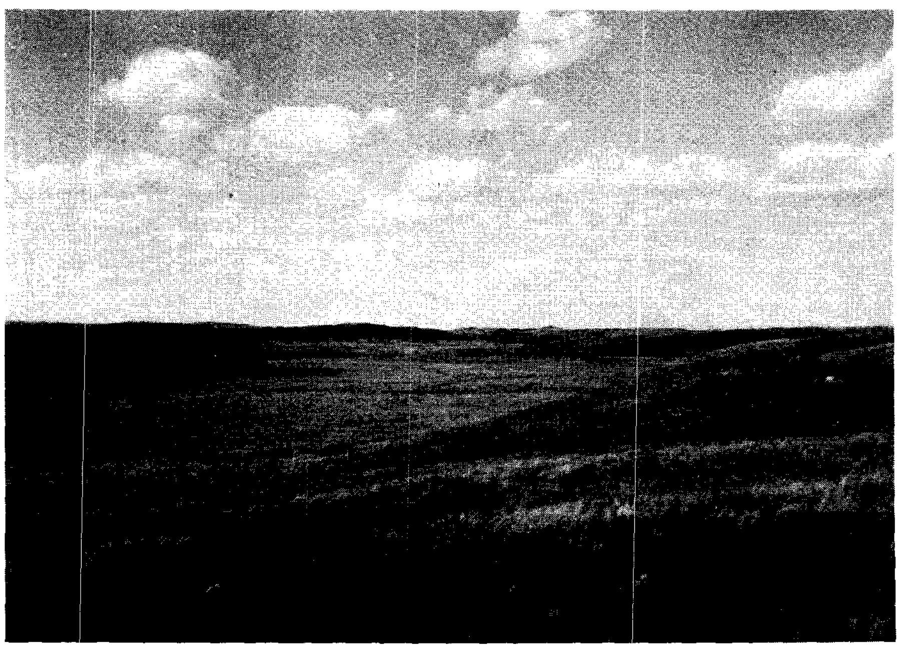

Figure 23. Meltwater channel. Sec. 16, T. 145 N., R. 64 W. This channel was occupied by the ancestral James River and was abandoned when the Kensal ice receded to the east opening a lower route. View is north.

organic, dark gray to black, silt and fine sand. The thickness of the alluvial material is largely unknown but shale crops out along the margins of the valley and in some places at water's edge. Several test holes near the town of Sheyenne in and near the valley penetrated more than 50 feet of alluvial fill in the central parts of the channel. Test holes nearer the margins of the valley penetrated less than 15 feet of fill. Numerous low terraces can be identified in various locations along the Sheyenne River but none of these can be traced for appreciable distances (pl. 3).

The lowest group of terraces consists of three surfaces. The Oberon fill terrace (1) in sec. 2, T. 150 N., R. 67 W. is very restricted and about 20 feet above the floodplain. The Gates fill terrace (2)

TABLE 1. ELEVATIONS OF TERRACES IN EDDY AND FOSTER COUNTIES.

Terrace	Elevation above sea level	Approximate height above floodplain
James River Terraces		
A. Munster terrace	1525-1550	5-15 feet
B. Pleasant Prairie cut terrace	1492-1496	10 feet
C. Brantford fill terrace	1480-1505	15-20 feet
D. Haven cut terrace	1460-1482	25 feet
E. Larabee cut terrace	1490-1505	30-40 feet
F. Bucephalia terrace	1495-1510	45-55 feet
G. Refuge cut terrace	1510-1515	60 feet
Sheyenne River Terraces		
1. Oberon fill terrace	1440-1450	20 feet
2. Gates fill terrace	1430-1450	35 feet
3. Bush cut terrace	1435	25 feet
4. Grandfield cut terrace	1450-1505	55-75 feet
5. Freeborn terrace	1440-1445	45-55 feet
6. Eddy terrace	1450-1460	65-75 feet
7. Valhalla cut terrace	1488-1505	75-80 feet
8. Hillsdale cut terrace	1472-1480	80-90 feet
9. Tiffany terrace	1495-1505	90-110 feet

near the town of Sheyenne is about 35 feet above the floodplain and is covered by very extensive gravel deposits which have been commercially developed in sec. 5, T. 150 N., R. 66 W. The Bush cut terrace (3) which occurs in sec. 12, T. 150 N., R. 65 W. is about 25 feet above the floodplain.

The second group of terraces consists of the Grandfield cut terrace (4) and the Eddy terrace (6) which are about 55 to 75 feet above the floodplain, and the Freeborn terrace (5) which is at the 45 to 55 foot level. Sand and gravel deposits of unknown thickness that occur on the Eddy terrace have been utilized locally.

The Valhalla (7) and Hillsdale (8) cut terraces comprise the third and most widely developed system of terraces. These terraces, which occur at heights between 75 and 90 feet above the floodplain, are moderately to highly dissected and commonly surfaced by outwash. The gravel is of little economic importance because of its high shale content.

The highest terrace level, Tiffany terrace (9), occurs only in the "big bend" area of the Sheyenne River in T. 150 N., Rs. 64 and 65 W. (pl. 4). It can be identified at elevations of 90 feet and more above the floodplain and probably is an ice-marginal feature. Everywhere restricted and vague, this level is highly dissected and commonly floored by till.

ECONOMIC GEOLOGY

Sand and Gravel

Sand and gravel occurs as ice-contact deposits, beneath river terraces, underlying outwash plains and as channel deposits. It is well distributed throughout Eddy and Foster Counties. Most of the gravel in the area occurs as river terrace deposits along the James and Sheyenne Rivers. Generally, ice-contact deposits are unsuitable for concrete aggregate and road surfacing because of a lack of sorting and high shale percentages. Some kames and eskers have been used locally by farmers for road surfacing and concrete aggregate, however. Deposits of outwash plains in the area are generally too shaly for economic production. Channel deposits are thin, usually silty, and not of economic importance. Plate 1 shows the location of the most important gravel pits.

Sand and gravel are mined in Eddy and Foster Counties by two commercial firms. The first and larger of these is Sheyenne Gravel and Sand, Inc., of Sheyenne, North Dakota. Located on 160 acres of land in the SW 1/4 of sec. 6, T. 150 N., R. 66 W. along the Sheyenne River, it operates the year round with an average of 12 employees. It produces an average of between 60,000 and 120,000 cubic yards of gravel in a year, 80 percent of which is washed. Most of the gravel is shipped south by rail or truck. The operation is served by a branch line of the Northern Pacific Railroad. Sand and gravel are mined here from the Gates fill terrace along the Sheyenne River. Although no accurate data exist on the reserves present beneath the terrace, test holes have penetrated 18 feet of gravel, and, at the present rate of production, enough gravel remains for 20 or 30 years.

The other commercial gravel company is owned by Elmer Anderson of Carrington, and it is located in the east half of sec. 4, T. 147 N., R. 65 W. southwest of Brantford. This is a considerably smaller operation and produces from 12,000 to 15,000 cubic yards of gravel a year. Production includes block sand, pea gravel and coarse gravel, and the equipment includes washing facilities. Test holes drilled by the North Dakota Highway Commission penetrated 17 feet of gravel. Estimated reserves are well over a million cubic yards. The pit is not served by a railroad but the main line of the Great Northern Railroad passes through Brantford, 1 1/2 miles away.

Ground Water

Most of the water used by farmers in Eddy and Foster Counties comes from gravel and sand aquifers within the glacial materials. Particularly good aquifers are those in northwestern Foster County (the Carrington aquifer), the northwest-southeast trending strip along the Great Northern Railroad tracks (the Heimdal aquifer), and those underlying smaller areas such as along Scotts Slough, Pipestem Creek and the James and Sheyenne River valleys. Most of the farm wells in glacial deposits are less than a hundred feet deep and yield hard, mineralized water. A few deep wells have penetrated bedrock, and water has been obtained from shale of the Pierre Formation and sand of the Dakota Formation, but the quality has been poor.

Local sources of ground water are usually sufficient for domestic use, but some farmers find it necessary to truck water to their farms. Locally, in the areas underlain by the better aquifers, some farmers irrigate, but irrigation on a large scale will require a much larger source of water.

Surface Water

Major streams in the area are the Sheyenne and James Rivers and Pipestem Creek. There are also numerous intermittent streams and innumerable lakes. Permanent natural lakes include Juanita Lake in Foster County, two miles east of Grace City; Horseshoe Lake on the Eddy-Benson County line three miles west of Warwick; North and South Washington Lakes and Lake Coe in T. 149 N., R. 63 W.; and Johnson Lake on the Nelson-Eddy County line six miles north of the southern edge of Eddy County. In addition, man-made reservoirs are located on both the Sheyenne and James Rivers and on Pipestem, Kelly and Bald Hill Creeks. The largest of these is Arrowwood Lake, located in the James River valley in Stutsman County and extending north of the Foster County line.

Numerous sloughs, intermittent ponds that may be entirely or in part filled with marsh, are present throughout the two counties. Small temporary lakes and sloughs are abundant in depressions resulting from irregular deposition of drift. Most of these lakes and ponds are floored with till or thin lake clays over till. Because the water in the lakes tends to be brackish, few fish and waterfowl are sustained, but in particularly wet years, such as the summer of 1962, many depressions are filled with fresh water and waterfowl are plentiful. The largest lake with a stable waterlevel, Juanita Lake, has recreation facilities developed on the shore.

Petroleum

Seventeen wells have been drilled for oil in Eddy and Foster Counties as of January 1, 1965. None of these has produced any oil and no oil shows were reported from any of the wells.

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 updip into the Carrington Shale occurs generally west of Foster County. The other occurs in western Foster County and to the south where the Carrington Shale facies seals the truncated Birdbear and Duperow Formations. The Duperow Formation produces oil in western North Dakota and the Birdbear has excellent porosity so Foster County should not be overlooked as a potential petroleum producer.

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