# Geology
# of
# Mountrail County
# North Dakota

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*By* Lee Clayton

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# PREFACE

This is volume IV of a four-volume report on the geology and groundwater resources of Burke and Mountrail Counties. Volume I is the geology of Burke County, volume II is a basic groundwater and well survey of Burke and Mountrail Counties, and volume III is a discussion of the groundwater resources of the two counties. Similar reports have been published for about half of the other counties in North Dakota.

Fieldwork for this report was completed during the summers of 1964, 1965, and 1966. Chester F. Royse, of the University of North Dakota, mapped the geology of seven townships (T. 155 N., R. 88 through 90 W. and T. 156 through 158 N., R. 90 W. and T. 158 N., R. 89 W.) in 1964. Clayton J. Grove, of Northwestern University, mapped six townships (T. 154 through 156 N., R. 93 W. and T. 155 through 157 N., R. 92 W.) in 1964. Robert G. Willson, of the University of North Dakota, mapped nine townships (T. 152 N., R. 89 through 91 W. and T. 153 and 154 N., R. 88 through 90 W.) in 1966. I mapped the remaining 31 townships during 1964, 1965, and 1966. The maps and text were compiled in 1967 and were slightly updated in 1970.

The maps and several of the figures were prepared by S. R. Deal. In addition, I wish to thank the following people for their contributions to this report: S. J. Tuthill, J. P. Bluemle, S. R. Moran, B. M. Arndt, and D. E. Deal.

Lee Clayton, 1970

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# HOW TO USE THIS REPORT

This volume is divided into two sections. Section A is a description of (a) the topography, (b) the rock and sediment, and (c) the general hydrology of Mountrail County. In addition, section A contains a brief summary of the age and origin of the topography, rock, and sediment of the county. Section A is written for those (especially nongeologists) who are interested in the physical nature of the near-surface earth materials underlying the county.

Section B of this volume is a more detailed discussion of the problems involved in determining the age and origin of the geologic materials and landforms in Mountrail County. This section is written for those (especially geologists) who are interested in the geologic processes and sequence of events during late Cenozoic time in this area.

*Contractors* and *civil engineers* interested in the gross characteristics of foundation materials at potential construction sites can determine the kinds of materials to be expected from map 1 in the envelope in the back of this volume. The reliability of the information on this map is indicated in the introductory part of chapter 2 of section A of this volume. The map is not precise enough for detailed construction needs but will provide the initial information for planning more detailed investigations. The gross characteristics of each of the formations at a site is given in chapter 2. The best foundation materials in Mountrail County are generally the sand and gravel of formations C, D, and E and the pebbly, sandy, silty clay of formation C, although the boulders in the pebbly, sandy, silty clay of formation C may be abundant enough in some places to cause excavation problems. Seepage water may be a problem in low-lying areas where any sand or gravel is present. Formations F, G, and H are highly variable. Some parts of these formations may provide excellent foundations. Other parts may provide very weak foundations, may rebound or creep into deep excavations, may be subject to landsliding, may contain cemented layers and lenses that are difficult to excavate, and may produce large amounts of seepage water from lignite or sand layers. The silt and clay of formation C generally provide rather poor foundations. Formation A provides very weak foundations. Seepage water and flooding are generally a problem in formations A and B.

Coarse *aggregate* is provided by the sand and gravel of formations B, C, and E. The content of fines, shale, chert, and other undesirable materials is highly variable.

Readers concerned about water *pollution* can find general information on this subject in chapters 2 and 3 of section A. In general, the danger of groundwater pollution by dumping of liquid wastes on the ground surface is greatest in groundwater recharge areas in highly permeable material such as the sand and gravel of formations C, D, E, F, G, and H. Groundwater may be polluted much more slowly (or not at all if the wastes break down with time) in recharge areas in slightly permeable material such as the silt and clay and pebbly, sandy, silty clay of formation C, the sandy, silty clay of formation D, and the silt and clay of formations F, G, and H. No pollution of groundwater by surface wastes can occur in groundwater discharge areas. In contrast, the greatest danger of pollution of surface water by liquid wastes occurs in groundwater discharge areas, and the least danger occurs in groundwater recharge areas in highly permeable material.

Readers interested in *economic minerals* can find information in chapter 2 of section A on lignite (formations G and H); ceramic clays (formation F, G, and H); and oil, gas, nitrogen, rock salt, and potash (subsurface formations).

Readers interested in *groundwater* can find general information on this subject in chapter 3, and more detailed information can be found in volumes II and III of Bulletin 55.

# SECTION A--DESCRIPTIVE GEOLOGY OF MOUNTRAIL COUNTY

The topography, the near-surface sediment, and the surface hydrologic features of Mountrail County are shown on map 1 in the envelope in the back of this volume. The topography (chapter 1), rock and sediment (chapter 2), hydrology (chapter 3), and geologic history (chapter 4), shown on this map are discussed below in greater detail.

## CHAPTER 1--TOPOGRAPHY

A pictorial representation of the topography of Mountrail County is shown in figure 1. A generalized contour map of the county is given in figure 2.

Mountrail County can be divided into five general topographic areas (fig. 1).

(1) In the northeast part of the county is a flat area, which is the westernmost part of the Drift Prairie, a generally level area covering much of the northeastern half of North Dakota.

(2) At the southwest edge of the Drift Prairie is a smooth slope called the Missouri Escarpment. It rises from an elevation of 2100 feet at the edge of the Drift Prairie to about 2250 feet at the top of the escarpment. Streams on the escarpment empty into the Des Lacs River, a tributary of the Souris River.

(3) At the top of the Missouri Escarpment is the Missouri Coteau. This is a hilly area that extends from east-central South Dakota northwestward into western Saskatchewan. The Missouri Coteau has numerous sloughs and lakes but is totally lacking in streams. The entire 20-mile width of this area is the continental divide between drainage into Hudson Bay and the Gulf of Mexico.

(4) Sloping southwestward from the Missouri Coteau is the Coteau Slope. This area has numerous streams that are tributaries to the Missouri River. Few lakes and sloughs exist here.

(5) At the southwestern edge of Mountrail County is the Missouri River trench. The sides of the trench consist of badland bluffs, and the bottom of the trench is occupied by Lake Sakakawea, which is at an elevation of about 1850 feet.

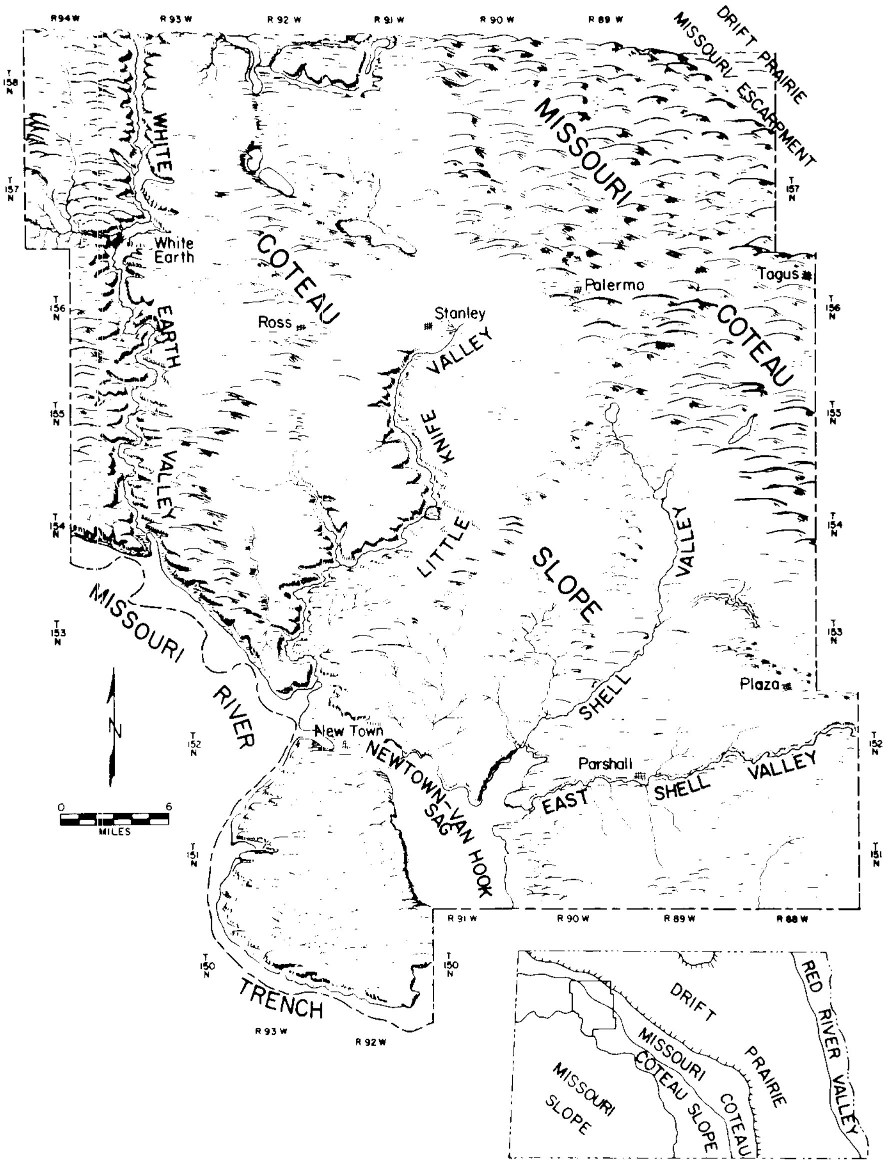

Figure 1.–Pictorial map of the topography of Mountrail County.

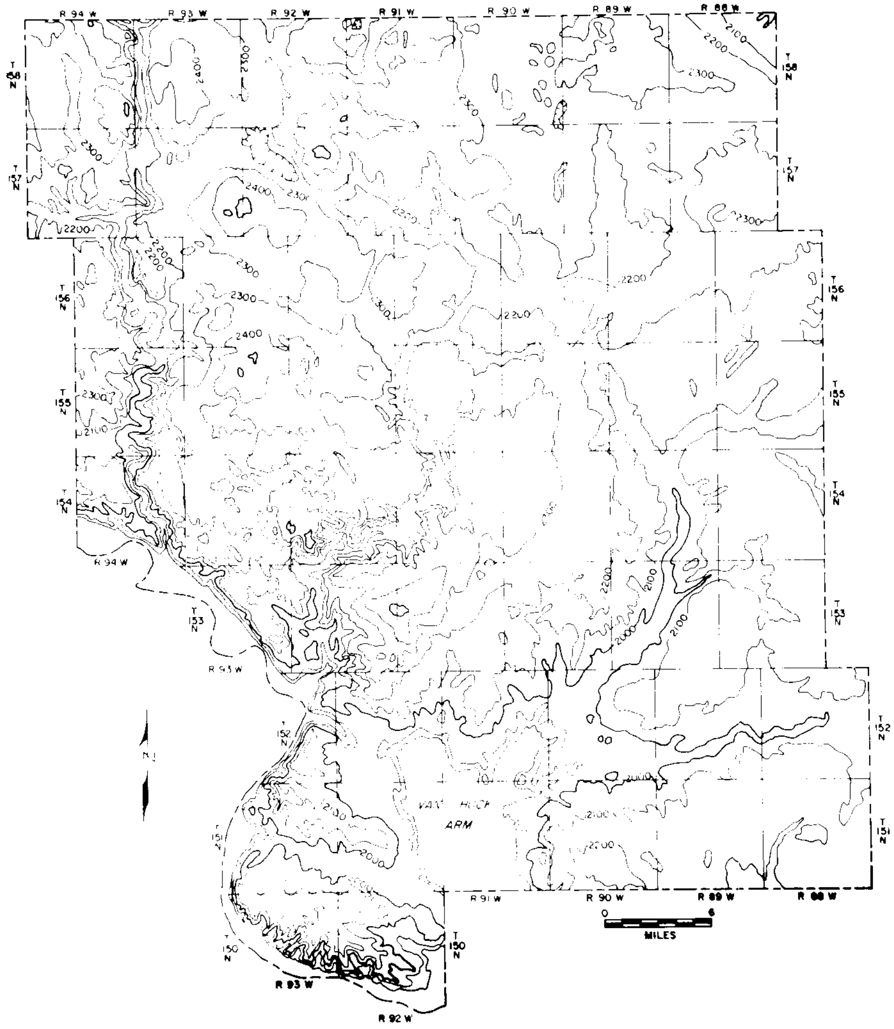

Figure 2.–Generalized contour map of Mountrail County (from U. S. Army Map Service 1:250,000 maps).

*Map units.*–Topography is indicated on map 1 by a white-line pattern. The map units are based on drainage integration and slope angles. Drainage is considered to be either integrated or nonintegrated.

Drainage is *integrated* where runoff is collected by streams; the topography consists of a complex of valleys (from a few tens of feet to many miles wide) separated by drainage divides. Small unmapped areas (as much as a few hundred acres) of nonintegrated drainage might be included in some of these map units, especially in divide areas.

Drainage is *nonintegrated* where runoff is collected by sloughs or lakes that have no outlets. Streams and stream valleys are lacking in these areas. Small unmapped areas of integrated drainage are included in some of these map units.

The distribution of areas of integrated and nonintegrated drainage was determined from airphoto stereographic pairs (scale 1:20,000).

These two broad categories of topography–integrated and nonintegrated drainage–are further subdivided on the basis of average maximum slope angles *(1)**. Map units called *"flat"* (average maximum slopes less than 1 degree or 2 percent), *"undulating"* (average maximum slopes of 1 to 4 degrees or 2 to 7 percent), and *"rolling"* (average maximum slopes of 4 to 7 degrees or 7 to 12 percent) occur in both areas of integrated drainage and areas of nonintegrated drainage. The map unit called *"hilly"* generally has average maximum slopes between 7 and 20 degrees or 12 and 36 percent in areas of nonintegrated drainage and between 7 and 25 degrees or 12 and 46 percent in areas of integrated drainage. The map unit called *"badlands"* has average maximum slopes of 25 degrees to as much as 90 degrees and occurs only in areas of integrated drainage; many badland slopes are barren of vegetation. The map units called *"apron"* are smooth, even slopes consisting of a series of coalescing surfaces shaped like fans or segments of low cones. Slopes are less than 1 degree or 2 percent at the toe of the apron and may be as much as 10 degrees or 18 percent at the apex of the individual fans or cones. Aprons occur only at the base of steeper slopes.

Map units "flat," "undulating," "rolling," and "hilly" generally contain small (5 to 20 feet high) nonrepresentative slopes or scarps that are steeper than 20 degrees or 36 percent. These unmapped scarps occur where groundwater seeps out at the edge of stream channels in areas of integrated drainage or at the edge of sloughs and lakes in areas of nonintegrated drainage.

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*Notes (italic numbers in parentheses) are listed at the end of section A.

# CHAPTER 2--ROCK AND SEDIMENT

Mountrail County is covered by dark surface soils to a depth of several inches. Beneath the surface soils are rock and sediment; these are of interest to geologists and are the main subject of this report. Sediment can be considered to be any natural earth material that can be excavated with a shovel; it is called "soil" by the civil engineer. In contrast, rock is any natural earth material that is too hard to be excavated or dug with a shovel and does not slake or disintegrate in water. In this report, the names of most types of rock (such as sandstone) can be distinguished from the names of sediment (such as sand) by the presence or absence of the suffix "stone"; the rock and sediment terminology used in this report is given at the end of section A *(2)*. Sediment predominates in the upper several hundred feet in this area, and rock predominates beneath that, deep into the earth. Only the upper 14,000 feet (depth of deepest oil wells) will be considered here.

The various rocks and sediments in this area are most easily characterized and described if they are subdivided into formations. A formation is a subdivision of the earth's crust that is recognized by observable physical characteristics *(3)*.

The nearly 50 formations that occur beneath Mountrail County will be discussed in order, starting with the uppermost and most familiar formations and ending with the deepest and least known formations. These formations are listed in table 1 and are shown in the cross-section through Mountrail County, in figure 3. The surface formations are shown on map 1 in the pocket at the end of this volume.

*Map reliability.*–Map 1 is based on field observation with interpolation between observation points on airphoto stereographic pairs. Shallow holes were dug to expose the material beneath the surface soil at several thousand points along all section-line roads and trails in the county; additional observations were made at numerous other points.

The degree of confidence in the location of the line of contact between different formations is indicated on map 1 by the nature of the line. A *solid line* indicates the greatest degree of confidence; the true location of the contact between formations is probably not more than 0.1 mile from the solid-line contacts shown on the map. These contacts are generally obvious on airphotos. A *dashed line* indicates somewhat less confidence in the true position of the contact between formations. A *dotted line* indicates the least degree of confidence; the true position of the contact is likely to be more than 0.3 mile from the dotted line in many areas. These contacts generally are not obvious on airphotos.

Table 1.–The formations underlying Mountrail County *(29)*.

| Sequence | Formation (or Group) | | General Character | Approximate Age | |
|---|---|---|---|---|---|
| Tejas | Formation A | | Black clay | Pleistocene<br>Holocene | Quaternary |
| | Formation B | | Gravelly sandy silt, etc. | | |
| | Coleharbor | | Slightly gravelly sandy silty clay; sand and gravel; silt and clay | | |
| | Formation D | | Gravel and sand | | |
| | Formation E | | Pebbly sand, silt | ?<br>Pliocene? | Tertiary |
| Zuni | Golden Valley | | Clay, sand, silt, sandstone | Eocene | |
| | Ft. Union Group | Sentinel Butte | Sand, silt, lignite, mudstone, sandstone | Paleocene | |
| | | Tongue River | Silt, sand, lignite, mudstone, sandstone | | |
| | | Cannonball | Sand, silt, mudstone, sandstone | | |
| | Hell Creek | | Sand, mudstone, siltstone, sandstone, lignite | Cretaceous | |
| | Fox Hills | | Siltstone, sand, sandstone | | |
| | Pierre | | Mudstone | | |
| | Niobrara | | Mudstone, calcareous | | |
| | Carlile | | Mudstone | | |
| | Greenhorn | | Mudstone, calcareous | | |
| | Belle Fourche | | Mudstone | | |
| | Dakota Group | Mowry | Mudstone | | |
| | | Skull Creek | Mudstone | | |
| | | Fall River | Sandstone, mudstone | | |
| | | Lakota | Sandstone, mudstone | | |
| | Morrison-Swift | | Mudstone, clay | Jurassic | |
| | Sundance-Rierden | | Mudstone, sandstone | | |
| | Piper | | Limestone, anhydrite, halite, mudstone | | |
| Absaroka | Spearfish | | Siltstone, halite, anhydrite, sandstone | Triassic | |
| | Minnekahta | | Limestone | Permian | |
| | Opeche | | Mudstone, siltstone, halite, anhydrite | | |
| | Minnelusa | | Sandstone, dolomite | Pennsylvanian | |
| | Amsden | | Dolomite, limestone, mudstone, sandstone | | |
| Kaskaskia | Big Snowy | Heath | Mudstone | Mississippian | |
| | | Otter | Mudstone, limestone | | |
| | | Kibbey | Mudstone, limestone, sandstone | | |
| | Madison | | Limestone, halite, anhydrite | | |
| | Bakken | | Siltstone, mudstone | | |
| | Three Forks | | Mudstone, siltstone, dolomite | Devonian | |
| | Birdbear | | Limestone | | |
| | Duperow | | Dolomite, limestone | | |
| | Souris River | | Dolomite, limestone | | |
| | Dawson Bay | | Dolomite, limestone | | |
| | Prairie | | Halite | | |
| | Winnipegosis | | Limestone, dolomite | | |
| Tippecanoe | Interlake | | Dolomite | Silurian | |
| | Stonewall | | Limestone, dolomite | Ordovician | |
| | Stony Mountain | | Limestone | | |
| | Red River | | Limestone, dolomite | | |
| | Winnipeg Group | Roughlock | Mudstone, siltstone | | |
| | | Icebox | Mudstone | | |
| | | Black Island | Sandstone | | |
| Sauk | Deadwood | | Limestone, mudstone, sandstone | Cambrian | |
| (Unnamed) | | | Igneous and metamorphic rock such as granite and gneiss | Precambrian | |

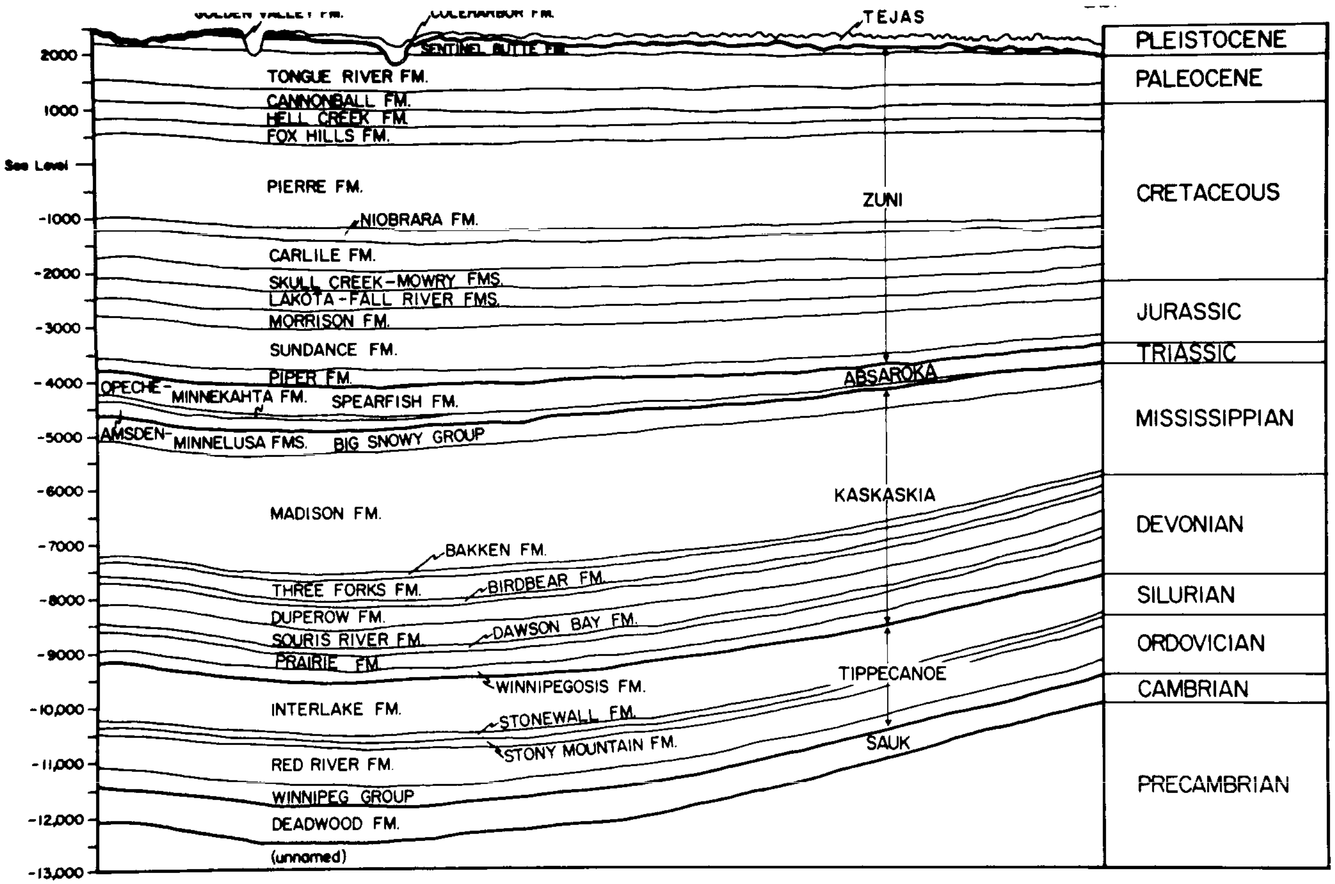

Figure 3.—Generalized east-west cross-section across Mountrail County showing the subsurface formations.

Surface occurrences of any formation that are less than a few hundred feet in diameter could not be shown on map 1. For this reason, and because of the lack of detailed fieldwork, single map-areas shown on map 1 generally contain other formations besides the one indicated by the color pattern. Small areas of other formations may occupy as much as 15 percent of many individual map-areas. For instance, the green hue on map 1 indicates that the sediment in these areas generally consists of the pebbly, sandy, silty clay of the Coleharbor Formation. However, many small unmapped areas of formation A, sand and gravel of the Coleharbor Formation, and silt and clay of the Coleharbor Formation also are present in most parts of the areas shown in green on map 1.

## Formation A

Formation A consists of as much as 20 or 30 feet of tough black clay, silty clay, and clayey silt that fills the bottoms of sloughs; it is everywhere underlain by the Coleharbor Formation. It contains several percent of organic material, causing the black color. Although little data is available, it is probably classified as CH, using Unified terminology *(4)* and A-7-6, using AASHO terminology *(5)*. The properties of formation A tend to be relatively uniform throughout Mountrail County.

Although water frequently stands in these sloughs, the groundwater level often drops well below the ground surface, and the clay of formation A is dry much of the time. In contrast, the sediment in the bottoms of intermittent or perennial ponds, lakes, or marshes is always moist. As a result, the sediment in intermittent or perennial ponds is very different from formation A. The clay of formation A has a natural moisture content, natural dry density, and compressive strength similar to the clay of the Coleharbor Formation. In contrast, the sediment of intermittent and perennial ponds have a much higher moisture content, a much lower natural dry density and compressive strength, and a much greater content of organic material.

Sloughs containing formation A are easily distinguished in the field from intermittent or perennial ponds. However, because there are several thousand of them in Mountrail County, only a small number of them were actually investigated. Instead, they were distinguished by their appearance on airphotos. This was a rather inaccurate procedure and many of them are probably incorrectly distinguished on map 1. Many hundreds of sloughs containing clay of formation A are too small to be mapped; only the larger ones are shown on map 1. On large-scale soil maps formation A is commonly indicated by the presence of Parnell and Dimmick soils.

The clay of formation A can usually be distinguished from the clay in the Coleharbor Formation; formation A contains several percent organic material and is generally free of calcium carbonate, whereas the Coleharbor Formation has little or no organic material and generally contains at least several percent calcium carbonate.

Formation A consists of sediment washed off adjacent hill-slopes by runoff water during the past 10,000 or more years. During periods of drought this process was accelerated because the stabilizing effects of the plant cover were decreased.

## Formation B

Formation B overlies parts of the Tongue River Formation, Sentinel Butte Formation, and Coleharbor Formation. It occurs in the bottoms of valleys now occupied by perennial or intermittent streams. It is several tens of feet thick in some areas.

Formation B consists of two different kinds of sediment: (a) sand and gravel and (b) silty sediment.

The sand and gravel of formation B is very similar to the sand and gravel of the Coleharbor Formation, but it occurs as lenses only a few feet thick within the silty sediment; the sand and gravel of the Coleharbor Formation is generally much thicker and is associated with pebbly, sandy, silty clay, silt, and clay–never with extensive amounts of pebble-free silty sediment.

The silty sediment makes up the bulk of formation B. It is commonly pebble free and consists of horizontal layers of clayey silt, sandy silt, silty clay, and sandy, silty clay *(2)* each a few inches thick. It generally contains several percent organic material, causing it to be very dark brown. It is somewhat cohesive and will stand in 15-foot vertical banks. Fossil snail shells are common in the sandy clayey silt, and bison bones are frequently found in it.

The groundwater level in formation B is generally at about the level of the adjacent river. Beneath this level, groundwater adequate for individual farms can sometimes be pumped from wells penetrating sand and gravel lenses within formation B or from underlying sand and gravel of the Coleharbor Formation.

Formation B was deposited by the present streams during the past 10,000 years. The sandy, clayey silt settled out of over-bank flood waters, and the sand and gravel were deposited as bars in the stream channels.

## Formation C: Coleharbor Formation

The most widespread, most uniform, and best known surface formation in Mountrail County is the Coleharbor Formation, named for the town of Coleharbor in McLean County. The formation is well exposed in the shore bluffs of Lake Sakakawea near Coleharbor *(6)*.

*Distribution*.–The Coleharbor Formation underlies about 90 percent of Mountrail County, as shown on map 1. It is more than 300 feet thick in the northeastern part of the county and thins to the southwest, as shown in figure 4.

The Coleharbor Formation is underlain in different areas by the Tongue River Formation, Sentinel Butte Formation, Golden Valley Formation, formation D, or formation E. It is overlain in many areas by formation A or formation B.

The Coleharbor Formation consists of numerous layers and lenses of different composition. Individual layers or lenses range from a few inches to many tens of feet thick and extend horizontally from a few feet to many miles. They can be grouped into three general categories: (a) pebbly, sandy, silty clay, (b) sand and gravel, and (c) silt and clay.

*Pebbly, sandy, silty clay*.–About 87 percent of the Coleharbor Formation in Mountrail County consists of pebbly, sandy, silty clays *(7)* . In Mountrail County it is a uniform nonbedded mixture of about equal parts of sand-sized, silt-sized, and clay-sized material, plus a few percent pebbles, and some cobbles and boulders as much as 10 feet in diameter *(8)*. Using USDA terminology *(9)*, it is largely clay loam. Using Unified terminology *(4)*, about 90 percent of it is CL and about 10 percent is CH *(10)*. About 35 percent of it can be classified as A-6 and 65 percent as A-7-6, using AASHO terminology *(5)*, based on 65 analyses of material from a depth of 0 to 100 feet; the average liquid limit is about 44 and the average plasticity index is 24 *(10)*. (Based on 25 analyses *(10)* from material at a depth of 0 to 5 feet, about half of it is A-6 and half is A-7-6.)

Based on several analyses of samples from depths of 0 to 5 feet *(10)*, the pebbly, sandy, silty clay of Mountrail County has maximum dry densities between 108 and 118 pounds per cubic foot, optimum moisture contents between 12 and 16 percent, and corrected California Bearing Ratios ranging from 9 to 24 at 55 blows per layer, 6 to 14 percent at 26 blows per layer, and 2 to 4 percent at 12 blows per layer.

Based on 180 analyzed samples from depths of 0 to 100 feet *(10)*, the pebbly, sandy, silty clay has a natural dry unit weight ranging from 100 to 118 pounds per cubic foot with an average of 111, a natural moisture content ranging from 18 to 24 percent with an average of 20.5 percent, and undrained triaxial compressive strength (consolidation

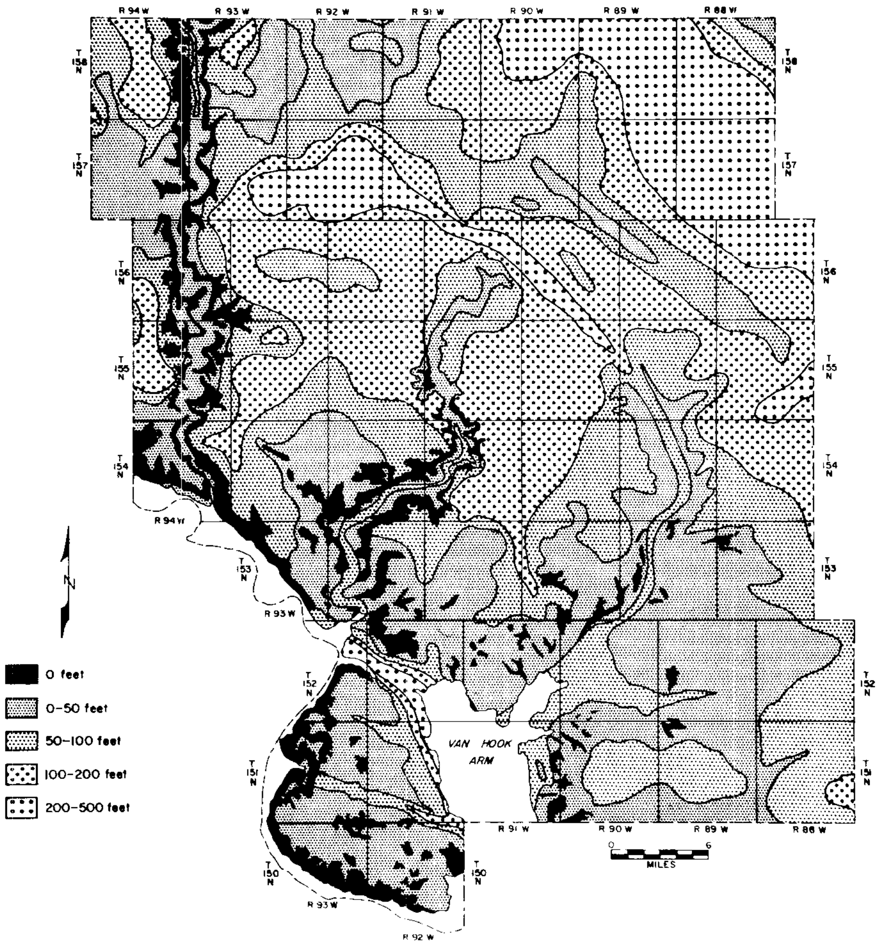

Figure 4.—Approximate thickness of the Coleharbor Formation in Mountrail County.

pressure equal to calculated overburden pressure) ranging from 20 to 80 pounds per square inch with an average of 44. Compressive strengths tend to increase with depth, with values ranging from 20 to 50 pounds per square inch at a depth of 20 feet and values ranging from 40 to 80 pounds per square inch at a depth of 100 feet.

The pebbly, sandy, silty clay is grayish brown above the water-table; beneath the water-table it is dark gray and is often called "blue clay" by drillers.

Like its other properties, the mineralogy of the pebbly, sandy, silty clay is probably more uniform than the mineralogy of most other sediment in the county. The clay-sized material is largely montmorillonite, other clay minerals, and some fine-grained calcite, dolomite, quartz, and feldspar. The silt-sized and sand-sized material consists largely of quartz and feldspar plus some limestone, dolomite, and shale fragments. The pebbles consist largely of limestone, dolomite, black shale, and various hard metamorphic and igneous rock types. The cobbles and boulders consist of various igneous and metamorphic rock types and lesser amounts of limestone and dolomite.

The pebbly, sandy, silty clay has low permeability. The permeability that does exist is largely the result of vertical fractures; the vertical permeability is therefore greater than the horizontal permeability. It is generally not a source of usable amounts of groundwater. Most of the groundwater in sand, gravel, or lignite beneath this material is recharged by infiltration of precipitation through the pebbly, sandy, silty clay.

*Sand and gravel.*–About 8 percent of the Coleharbor Formation consists of layers and lenses of sand and gravel *(7)*. They are largely sandy gravel, gravelly sand, and dirty sandy gravel, with minor amounts of slightly gravelly sand *(2)*. Using Unified terminology *(4)* it is classified as SM, SC, GC, SP, GP, SW, or GM, in approximate decreasing order of abundance *(10)*. Using AASHO terminology *(5)* most is classified as A-1 or A-2.

This material is much more variable in grain-size composition than pebbly, sandy, silty clay of the Coleharbor Formation. Large variations within short distances are common. If sand or gravel of a particular grain size is wanted, the areas shown in orange on map 1 must be sampled in detail to determine favorable locations. A couple of rough generalizations about grain-size variations can be made, however. The sand and gravel in the hilly areas in the northeastern part of the county is the poorest sorted (best graded) and coarsest grained; maximum grain size is generally between 3 and 10 inches, though much larger boulders may be present. The sand and gravel in flat areas and valley bottoms in the southern part of the county tends to be the best sorted (poorest graded) and the finest grained; maximum grain size is no more than 1 or 2 inches in some areas. For a few feet beneath the ground surface, the sand and gravel generally contains greater amounts of silt and clay.

Mineralogically, the sand and gravel of the Coleharbor Formation has about the same composition as the sand-sized and gravel-sized material in the pebbly, sandy, silty clay, but with a lower percentage of shale and other soft material. The sand is largely quartz and feldspar with some limestone and shale fragments and dark minerals. The gravel consists largely of limestone, dolomite, and granite and other hard igneous and metamorphic rock types. It may also contain as much as 10 percent shale, claystone, lignite, iron-oxide fragments, or other soft and crumbly materials. The bottoms of near-surface pebbles are generally coated with a crust of calcium carbonate. One percent or more of chert is present in much of the gravel. (Porphyry pebbles, which are abundant in formation D and formation E, are rare in the Coleharbor Formation.)

Most of the sand and gravel in the Coleharbor Formation is noncohesive. At the base of the formation and low on the sides of valleys, however, some of it is cemented with reddish-brown, iron-oxide-rich material, forming a hard conglomerate. The limestone and dolomite pebbles have been weathered out of much of this conglomerate, leaving voids. This reddish conglomerate is exposed in the bluffs of Lake Sakakawea, 1 mile northeast of the Four Bears Bridge (NE¼ NW¼ sec. 14, T.152 N., R. 93 W.). It is also exposed in roadcuts in the Little Knife River valley in NW¼ NE¼ sec. 17, T. 153 N., R. 93 W., and SE¼ NE¼ SE¼ sec. 36, T. 154 N., R. 93 W., and in the White Earth valley in SW¼ NW¼ and NW¼ SW¼ sec. 36, T. 157 N., R. 94 W.

The sand and gravel is generally horizontally layered. The layering in the hilly sand and gravel in the northeastern part of the county is generally tilted and faulted.

Many of the deposits of sand and gravel that are too small to show on map 1 are indicated by the symbol for sand and gravel pits. The two largest pits in the county are along the Burlington Northern Railway, 2 miles southeast of Blaisdell and a half mile west of Palermo.

Most of the sand and gravel has a very high permeability. It is the largest source of high-quality groundwater in Mountrail County.

*Silt and clay.*–About 5 percent of the Coleharbor Formation consists of layers and lenses of silt and clay *(7)*. It is largely free of pebbles and contains little sand; it is largely silty clay, clayey silt, and clay with some silt and sandy silt *(2)*. Using USDA terminology *(9)*, most of it is classified as silty clay, silty clay loam, and silt loam with some clay and silt. Using Unified terminology *(4)*,most of it is ML or CL with some CH *(10)*. Using AASHO terminology *(5)*, much of it is probably A-7-6 with lesser amounts of A-6. Based on analysis of only a few samples *(10)*, the natural dry unit weights, the natural moisture contents, and the compressive strengths of the silt and clay are about the same as those of the pebbly, sandy, silty clay in the Coleharbor Formation; the optimum moisture contents, liquid limits, and plastic indexes are somewhat higher; and the maximum dry densities are somewhat lower.

Mineralogically, the silt and clay in the Coleharbor Formation is the same as the silt and clay fraction of the pebbly, sandy, silty clay: clay minerals (especially montmorillonite), quartz, calcite, dolomite, and feldspar.

Unlike the pebbly, sandy, silty clay of the Coleharbor Formation, the silt and clay generally has horizontal layering a fraction of an inch in thickness. Its permeability and color are similar to those of the pebbly, sandy, silty clay.

The various properties of the silt and clay are less uniform than those of the pebbly, sandy, silty clay of the Coleharbor Formation. The silt and clay shown on map 1 in the hilly northeast third of the county has the highest clay content; most would be classified as silty clay or clay *(2)*. Most of the silt and clay in the undulating or rolling areas in the central and southeastern parts of the county is siltier; it is largely clayey silt or silty clay. A detailed physical and chemical analysis of silt and clay of the Coleharbor Formation from four localities in Mountrail County is given in North Dakota Geological Survey Miscellaneous Series 30-C.

One particular body of silt and clay of the Coleharbor Formation is distinctive enough to be described separately. It is best exposed in 50-foot shore bluffs of Lake Sakakawea ¾ mile north of Crow Flies High Butte (SW¼ SE¼ sec. 11, T. 152 N., R. 93 W.), where it is underlain by cemented gravel of the Coleharbor Formation. It is tan silt and clayey silt in a uniform sequence of hundreds of horizontal layers, ½ to 4 inches in thickness. It fills the New Town sag (fig. 1) to at least ½ mile southeast of New Town. It is overlain by sand and gravel of the Coleharbor Formation at an elevation of about 2,000 feet in much of the western part of the New Town sag. This body of silt and clay is more than 200 feet thick *(12)*.

*Identification of Coleharbor Formation.*–The only formation in Mountrail County containing pebbly, sandy, silty clay is the Coleharbor Formation. The only other formations that contain gravel are formation B, formation D, and formation E. The pebbles in the last two are largely quartzite and porphyry, not limestone, dolomite, and granitic rock types, as in Coleharbor gravel. The pebbles in formation B are identical to those in the Coleharbor Formation, however. Formation B is restricted to valley bottoms and contains large amounts of poorly-sorted sandy silt that is dark brown and contains a significant amount of organic material; this kind of sediment is uncommon or lacking in the Coleharbor Formation. Formation A is much more clayey, is much darker colored, and has a much higher content of organic material than the silt and clay of the Coleharbor Formation, and it always occurs in the bottoms of sloughs.

*Age and origin.*–The Coleharbor Formation was deposited during the ice ages (the Pleistocene Epoch) probably between several hundred thousand years and about 9000 years ago. The pebbly, sandy, silty clay is largely glacial sediment ("till"), consisting of material eroded by the Pleistocene glacier from northern North Dakota, Saskatchewan, and Manitoba. Most of this glacial sediment was deposited when it slumped or flowed to its present position as the last of the glacial ice melted.

Most of the silt and clay in the Coleharbor Formation was deposited from lakes that were surrounded by stagnant glacier ice at the end of the ice age. The silt in the New Town sag was deposited in the old Missouri River trench when the last glacier dammed the trench east of New Town, forcing the river 10 miles farther south, where it now flows. Some of the silt and clay in the Coleharbor Formation may also have been deposited in nonglacial lakes.

The sand and gravel of the Coleharbor Formation was for the most part deposited by rivers that were much bigger than the present Shell Creek, Little Knife River, or White Earth River. Many of the rivers were fed by water from melting glaciers. However, much of the uppermost Coleharbor sand and gravel was deposited by nonglacial rivers 10,000 to 13,000 years ago when annual precipitation was several inches greater and runoff was several times greater than at present. Some of the sand and gravel in the Coleharbor Formation is beach sediment that was deposited around ice-walled lakes in the central part of the county or around postglacial lakes such as White Lake.

## Formation D

*Distribution.*–Formation D occurs at the surface in a 5-square-mile area 6 miles southwest of New Town (map 1). Here it is as much as 300 or 400 feet thick. It fills a 2-mile-wide valley that has been cut into the Sentinel Butte and Tongue River Formations. Its base is at an elevation of about 1600 feet (depth of 422 feet in NDSWC test hole 3470 in SE¼ sec. 22, T. 151 N., R. 93 W.), and its top is at an elevation of about 2000 feet (highest surface exposures).

Test drilling has shown that formation D is buried under the Coleharbor Formation in other parts of Mountrail County. The material discussed in the previous paragraph extends eastward down the valley beneath Muskrat Lake and Van Hook Arm (fig. 5); it is present at a depth of about 145 feet at the east end of Muskrat Lake *(13)*. Here it is joined by another body of similar material buried in the New Town-Van Hook valley; it occurs between depths of about 110 to 300 feet in three test holes between New Town and Muskrat Lake *(14)*. Formation D may also be present beneath the Coleharbor Formation in the broad valley between the towns of White Earth and Ross *(15)*, in a buried valley southeast of the town of Belden *(16)*, and in a buried valley northeast of Palermo *(17)*.

Formation D consists of two distinctly different materials, sand and sandy, silty clay.

*Sand*.–About two-thirds of formation D consists of layers of sand that are 50 to 150 feet thick. It is well graded (poorly sorted) fine to coarse sand. It differs from sand in the Tongue River, Sentinel Butte, and Golden Valley Formations in being noncohesive and having pebbles scattered throughout *(2)*.

The composition of the pebbles is strikingly different from those in the slightly gravelly or gravelly sand in the Coleharbor Formation. They consist of very resistant rock types such as quartzite, hard argillite, porphyry, and chert (derived from the Black Hills or Rocky Mountains) and mudstone, chalcedony, agate, petrified wood, and scoria (derived from the Tongue River Formation and younger formations). The pebbles are similar in composition to those of formation E and those in the Flaxville Formation in Montana and adjacent areas. In contrast, the pebbles in the Coleharbor Formation are in large part limestone, dolomite, black shale, and granitic rock types derived from the northeast. The pebbles in the sand of formation D are commonly subangular or subrounded and are less than ½ inch, or at most 1½ inches in diameter.

A layer of sand at the top of the formation is exposed in an old borrow pit and in gullies at elevations of about 1950 to 2000 feet in S½ SW¼ sec. 5 and N½ NW¼ sec. 8, T. 151 N., R. 93 W. Other exposures occur along the road in NE¼ sec. 20, T. 151 N., R. 93 W. In NDSWC test hole 3470 (SE cor. sec. 22, T. 151 N., R. 93 W.) sand of formation D occurs from depths of 22 to 78 feet and depths of 98 to 212 feet.

The sand has high permeability and locally is an important source of groundwater.

*Sandy, silty clay*.–The sandy, silty clay layers in formation D are 20 to 100 feet thick. They are faintly bedded and cohesive and resemble some layers of the Sentinel Butte Formation. However, the sediment is not as hard and contains large amounts of sand-size lignite fragments and much more sand-sized mica than the Sentinel Butte Formation. In some places it contains pebbles of the same composition as those in the sand. Except for the pebble composition, this material could be mistaken for pebbly, sandy, silty clay of the Coleharbor Formation.

A layer of sandy, silty clay is well exposed in roadcuts in NW¼ sec. 21, T. 151 N., R. 93 W. In NDSWC test hole 3470, it occurs from depths of 78 to 98 feet and 307 to 422 feet.

*Age and origin*.–The age of formation D is unknown. It underlies the Coleharbor Formation and contains no pebbles derived from the north, so it was deposited before the late Pleistocene glaciations. The coarser-grained part of formation D resembles the finer-grained part of the Flaxville Formation, and therefore might have been deposited near the end of the Tertiary Period or during the early part of the Pleistocene Epoch, possibly a million or more years ago.

Formation D was deposited by a large river flowing northeastward from the Rocky Mountains or the Black Hills. The sand was deposited as channel bars and the sandy, silty clay settled out of overbank flood waters.

### Formation E

Gravel underlies the Coleharbor Formation and formation D and overlies the Tongue River and Sentinel Butte Formation at several places in the county. The gravel is poorly known; it is not assigned to any previously named formation, though it could be part of the Flaxville Formation; it is here called formation E.

The gravel is exposed at the surface south of New Town in a gravel pit in sec. 2, T. 151 N., R. 93 W., and at the sides of prominent small hills in sec. 31 and 32, T. 151 N., R. 92 W. It is a sandy gravel with pebbles and cobbles that consist of resistant quartzite, prophyry, chert, argillite, and other hard rock types. It was deposited by rivers flowing from mountains in South Dakota, Wyoming, or Montana. It differs from the gravel in the Coleharbor Formation, which contains limestone and granite pebbles that came from Manitoba and Saskatchewan. Drill holes have penetrated similar gravel beneath the Coleharbor Formation and formation D at several places in the county *(18)*.

This gravel was deposited by rivers during the early part of the Pleistocene Epoch, or possibly during the last part of the Tertiary Period.

## Formation F: Golden Valley Formation

*Distribution.*–The Golden Valley Formation overlies the Sentinel Butte Formation at elevations from about 2300 feet in the Little Knife valley to about 2400 feet in the upper White Earth valley. In most areas it is overlain by the Coleharbor Formation. The Golden Valley Formation occupies the highest upland areas in Mountrail County; its distribution is shown on figure 5. It can be seen at the edges of the uplands, especially along the Little Knife and upper White Earth valleys (map 1). The formation is as much as 200 feet thick.

The Golden Valley Formation occurs as isolated remnants throughout southwestern and western North Dakota. It was named for the town of Golden Valley in Mercer County. The northernmost known occurrence of this formation is in Mountrail County.

The Golden Valley Formation is similar to the underlying Sentinel Butte Formation. It is distinguished from the Sentinel Butte Formation by its much brighter colors, greater amounts of mica and kaolinite clay, and lack of thick lignite.

The Golden Valley Formation can be subdivided into two members *(19)*.

*Upper member.*–The upper member is subdivided into an upper clayey unit and a lower sandy unit. The upper clayey unit has not been seen at the surface in Mountrail County but is covered by 30 to 50 feet of the Coleharbor Formation. This clayey unit is known only from three auger holes northwest of the Little Knife valley *(19)*. It consists of silty clay, clay, and some clayey silt *(2)*. The clay layers are very tough, waxy bentonite, which is brilliant green or blue beneath the water-table (the bentonite quickly oxidizes to light brown on exposure to air). Three or four bentonite beds that are as much as 3 feet thick were penetrated by the auger.

The lower unit of the upper member is about 70 feet thick. It consists of fine sand, and very fine sand, and lesser amounts of sandstone, silty sand, sandy silt, clayey silt, and silty clay *(2)*. It is light brown or gray. The sand and silt is conspicuously crossbedded. It is largely quartz but contains considerable mica. Hard sandstone in this member is much less abundant in Mountrail County than to the south in McKenzie County, where it caps the Blue Buttes. The top of the upper member is covered and has not been observed in Mountrail County.

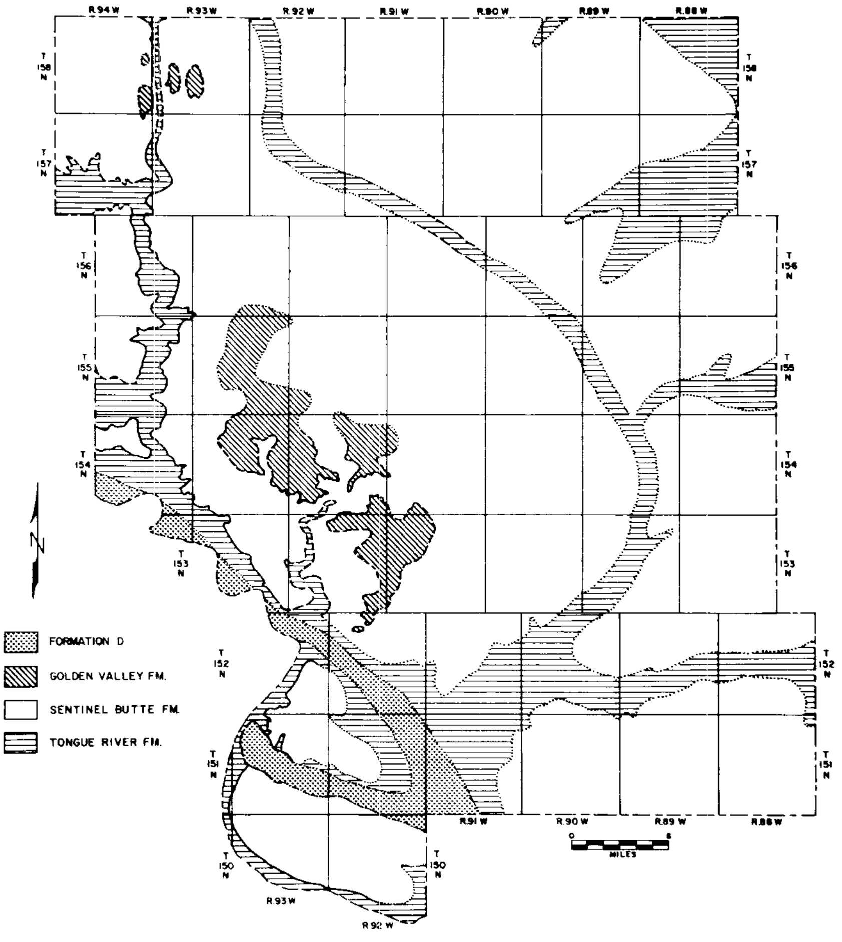

Figure 5.—Sub-Coleharbor formations in Mountrail County.

*Lower member*.–The lower member of the Golden Valley Formation is about 30 feet thick. It can be subdivided into three units: (a) the upper gray silt and clay unit, (b) the middle white or orange clay unit, and (c) the lower gray silt and clay unit.

The upper unit is 3 to 5 feet thick. It is a thinly-laminated, dark gray, silty clay that in many places has a lavender tinge. In some areas it has a thin lignitic zone at the top. The upper unit contains a 6-inch thick, hard, siliceous layer in some areas *(20)*.

The middle unit is 10 to 25 feet thick. It is clay or silty clay with some clayey silt, sandy clay, or sandy silt *(2)*. It is white or yellow, making this the most conspicuous clay unit in the Little Knife and upper White Earth valleys.

Mineralogically the middle unit is mainly kaolinitic clay and quartz *(21)*. Small flakes of mica are common. The yellow staining is the result of limonite nodules 1 or 2 mm in diameter. Several samples of this unit in Mountrail County have been analyzed; they have between 12 percent and 26 percent alumina ($Al_2O_3$) content *(22)*. It has been estimated that there are 25,000,000 tons of clay with a 20 percent to 25 percent alumina content under an average overburden of 40 feet in the upper White Earth valley *(22)*. This is one of the highest grade ceramic clays in North Dakota *(23)*. The middle unit of the lower member is the source of clay used at the brick plant at Hebron and the sewer-pipe plant at Dickinson, two of the major ceramic plants in the state.

The lower unit of the lower member is about 10 feet thick. It is a thinly-layered, gray silty clay or clayey silt.

*Age and origin*.–The Golden Valley Formation was deposited near the end of the Paleocene Epoch and during the first part of the Eocene Epoch, about 60,000,000 years ago. The clay and silt of the lower member were deposited in lakes or ponds on river floodplains. The sand of the upper member was deposited as river point-bar sediment. The clay and silt of the upper part of the upper member were probably deposited from flood waters in shallow basins on river floodplains; the bentonite might be weathered ash that was blown from volcanoes hundreds of miles to the west.

## Formation G: Sentinel Butte Formation
## and
## Formation H: Tongue River Formation

The Fort Union Group consists of three closely related formations (table 1). Only the upper two, the Sentinel Butte Formation and the Tongue River Formation, occur at the surface in Mountrail County. They are alike in many ways and will be described together *(24)*.

*Distribution*.–The Tongue River Formation is a horizontal layer about 600 feet thick underlying the Sentinel Butte Formation throughout most of Mountrail County. Along the Missouri River bluffs and in the White Earth River valley, the Tongue River Formation is at the surface, as shown on map 1. In these areas, the Sentinel Butte Formation and the upper part of the Tongue River Formation have been eroded away. The Sentinel Butte Formation is about 300 feet thick where it is overlain by the Golden Valley Formation. The surface occurrences of the Sentinel Butte Formation in Mountrail County are shown on map 1, and the areas where it occurs immediately beneath the Coleharbor Formation are shown in figure 5.

The Tongue River Formation underlies the western half of North Dakota and much of eastern Montana and parts of Wyoming and Saskatchewan; it was named after a tributary of the Yellowstone River in southeastern Montana. The Sentinel Butte Formation may be largely restricted to the western half of North Dakota; it was named after Sentinel Butte in Golden Valley County. The Fort Union Group was named after the 19th century fur-traders' post at the mouth of the Yellowstone.

The Sentinel Butte and Tongue River Formations consist of numerous layers (beds, strata, or seams). The individual layers range from a fraction of an inch to many feet in thickness and are nearly horizontal. They are of various compositions, which can be grouped into six general categories in order of decreasing abundance: (a) silt and clay, (b) sand, (c) lignite, (d) sandstone, (e) scoria, and (f) limestone.

*Silt and clay*.–The various silt and clay layers make up about 60 percent of the Sentinel Butte Formation *(25)*. Although an adequate sampling has not been made in Mountrail County, probably about 80 percent of the Tongue River Formation consists of silt and clay layers *(24)*.

Individual layers range from a few inches to a few tens of feet thick. Most are either clayey silt, silty clay, sandy silt, or silt (many of the layers might also be called mudstone or shale *(2)*, or silt loam, silty clay, silty clay loam, or silt, using the USDA terminology *(9)*. Using the

Unified terminology *(4)*, much of this material is classified as ML and a lesser amount as CL or CH *(10)*. Although the strength of the silt and clay is probably largely the result of compaction rather than cementation, more than half of it has been considered to be rock (shale) rather than sediment or soil *(10)*. Probably much of the silt and clay would be classified as A-7-6, using AASHO terminology *(5)*; the plasticity index was greater than 40 and the liquid limit was greater than 10 in a half-dozen analyzed samples *(10)*.

Based on 44 analyzed samples from depths of 0 to 100 feet *(10)*, the various silt and clay layers have a natural dry unit weight ranging from 96 to 108 pounds per cubic foot with an average of 104, a natural moisture content ranging from 22 to 31 percent with an average of 24.5 percent, and undrained triaxial compressive strength (consolidation pressure equal to calculated overburden pressure) ranging from 25 to 200 pounds per square inch with an average of 100.

The approximate mineralogical composition of the silt and clay layers is as follows.

(a) Several tens of percent of very fine-grained quartz and feldspar *(24)*.

(b) A few tens of percent of clay minerals, probably in large part sodium montmorillonite in groundwater discharge areas and below a depth of about 200 feet in groundwater recharge areas and calcium montmorillonite down to a depth of about 200 feet in groundwater recharge areas *(11)*.

(c) About 5 percent carbonates (calcite and some dolomite) in the Sentinel Butte Formation and about 10 percent in the Tongue River Formation *(24)*.

(d) Minor amounts of other minerals, such as iron oxides, marcasite, gypsum.

Some layers with high clay content may be of possible commercial value. A light-colored layer, about 10 feet thick, in the center of sec. 10, T. 157 N., R. 94 W., has an alumina ($Al_2O_3$) content of 15 percent and a silica ($SiO_2$) content of 54 percent *(22)*. The clays of the Tongue River and Sentinel Butte Formations in North Dakota have been evaluated as a possible commercial source of alumina in North Dakota Geological Survey Report of Investigation 33.

Some clay may be of ceramic value. In other parts of the state, some Tongue River and Sentinel Butte clay has been found to be suitable for making brick and lightweight aggregate. The clay of North Dakota is evaluated in Reports of Investigations 13 and 17 of the North Dakota Geological Survey and in "Mineral Resources of North Dakota" *(23)*.

Landslides commonly occur in silt and clay of these formations where slopes are steep. Landslides are common in areas of Sentinel Butte Formation having badlands topography, and to a lesser degree, in hilly topography (map 1). Stable natural slopes are generally no steeper than 30 degrees (60 percent) to 50 degrees (120 percent), although landsliding may occur on more subdued slopes on both the Tongue River and Sentinel Butte Formations. Much knowledge on the engineering characteristics of the Sentinel Butte Formation was gained during the construction of Garrison Dam *(26)*.

The silt and clay has a rather low permeability, much lower than the lignite and sand layers in both formations. Most of the permeability is a result of numerous closely-spaced fractures. The silt and clay is seldom a source of usable amounts of groundwater. However, the groundwater in most of the lignite and sand layers (both of which are important sources of groundwater in Mountrail County) is recharged through overlying silt and clay layers.

*Sand*.–Sand layers make up about 35 percent of the Sentinel Butte Formation *(25)* and perhaps 15 percent of the Tongue River Formation *(24)*.

Most of the sand can be classified as silty fine-sized to medium-sized sand *(2)* and sandy loam or loamy sand using USDA terminology *(9)*. It is classified as SM using Unified terminology *(4, 10)* and A-2 (probably in large part A-2-7) using AASHO terminology *(5)*.

Based on 33 analyzed samples from depths of 0 to 100 feet *(10)* the sand has a natural dry unit weight ranging from 100 to 110 pounds per cubic foot with an average of 106, a natural moisture content ranging from 11 to 25 percent with an average of 18 percent, and undrained triaxial compressive strength (consolidation pressure equal to calculated overburden pressure) ranging from 30 to 250 pounds per square inch with an average of 155.

The sand is very cohesive and forms a hard, rilled surface where it is exposed along river bluffs. Hillslopes of this material, especially at the base of the Sentinel Butte Formation, are commonly as steep as 70 degrees (275 percent). However, where the sand lies beneath the water-table, it is less cohesive and tends to flow into drill holes as quicksand.

The mineralogical composition of the sand is largely quartz and feldspar, with minor amounts of heavy minerals and fine-grained carbonate and clay minerals. Concretions of carbonate-cemented sand several inches in diameter are common.

Several sand layers 5 to 50 feet thick occur in the Sentinel Butte Formation; sand layers are generally thinner in the Tongue River

Formation. One wide-spread layer of sand at the base of the Sentinel Butte Formation is as much as 100 feet thick; it is exposed at the base of the Missouri bluffs in the southern part of the county, near the top of the bluffs northwest of New Town, along the sides of the White Earth valley, and near Parshall.

The sand layers in the Tongue River and Sentinel Butte Formations are an important source of groundwater in Mountrail County. The thick sand layer at the base of the Sentinel Butte Formation supplies water to several wells in the Stanley area, where it is at a depth of about 200 feet *(27)*; it is probably also the source of groundwater in many wells in southeastern Mountrail County. However, the high silt and clay content in the sand decreases its permeability; it has rather low yields of groundwater.

*Lignite*.–North Dakota lignite occurs primarily in the Ludlow, Tongue River, and Sentinel Butte Formations. In Mountrail County, several dozen lignite layers from an inch to a few feet thick make up about 3 percent of the two formations. Layers 10 to 15 feet thick are occasionally reported in drill-hole logs *(10, 25)* or in mines *(28)*. Large, clear crystals of gypsum (selenite) are commonly associated with the lignite beds.

The locations of abandoned lignite mines in Mountrail County are shown on map 1. Most of these mines are small surface pits that were formerly used as local sources of household fuel. The lignite in most of these pits was discovered by digging around springs; most springs in Mountrail County come from lignite layers. For this reason the symbols for spring and mine on map 1 are somewhat interchangeable; most springs are small lignite pits and most lignite pits have springs.

Most of the older commercial mines were underground. Underground mines along river bluffs entered lignite layers horizontally. Some mines had vertical shafts down to the lignite; one, in sec. 7, T. 154 N., R. 89 W., was 90 feet deep.

In the 1940's, strip mines replaced underground mines. They have been worked only intermittently since 1952. The largest mines in Mountrail County are 1 mile east of New Town and 1 mile south of Parshall.

Detailed surveys of the lignite have been made in the southern part of the county. The thickness and distribution of some of the major layers are given in several published reports *(28)*. There is an estimated reserve of nearly one billion tons of lignite in layers thicker than 5 feet in Mountrail County. Only about a quarter of a million tons have been mined to date. Thick overburden in most places prevents the lignite from being of very great commercial value at the present time.

Lignite has numerous fractures and therefore has a high permeability. It is one of the important local sources of groundwater in the southwestern half of Mountrail County where sand and gravel of the Coleharbor Formation is scarce. Along valley bottoms, springs from lignite have been developed for cattle and for domestic use, and in upland areas farm wells penetrate to the first lignite or sand having adequate groundwater.

*Sandstone.*–Less than 1 percent of the Tongue River and Sentinel Butte Formations is sandstone *(25).* Sandstone occurs as lenses or discontinuous layers only a few feet thick. It generally occurs within sand layers and forms resistant ledges along river bluffs. The sandstone is cemented with calcium carbonate. In contrast to the uncemented sand layers, it is no less cohesive beneath the water-table and is much harder to drill through.

*Scoria.*–Scoria is a natural brick that formed when lignite layers caught fire (possibly started by prairie fires) and baked the overlying silt and clay or sand layers. (The term "scoria" is used in other areas for porous material of volcanic origin.) This hard, red material is used in North Dakota for road surfacing, especially southwest of the Missouri River where gravel is scarce. Conspicuous occurrences of scoria in Mountrail County are 2 miles north-northwest of New Town and west of the mouth of White Earth River. Two small scoria pits occur a half mile northeast of New Town (a quarter mile west of the southeast corner of sec. 8, T. 152 N., R.92 W.) and in the White Earth valley in SW¼ NE¼ sec. 10, T. 155 N., R. 94 W.

*Limestone.*–Hard, dense limestone lenses a few feet thick occur throughout the Tongue River and to a lesser extent the Sentinel Butte Formation *(24, 25).*

*Distinguishing the two formations.*–The Tongue River and Sentinel Butte Formations are alike in many ways. They are distinguished in Mountrail County primarily by the presence of a thick sand layer at the base of the Sentinel Butte Formation and by their different colors *(24).* Beneath the water-table both are generally greenish gray or bluish gray. However, where they are exposed in badlands bluffs, the Sentinel Butte Formation tends to be dull gray or brownish, whereas the Tongue River tends to be brighter yellow. (However, at least one 15-foot yellowish bed occurs in the Sentinel Butte Formation 150 feet above Lake Sakakawea at the southern edge of the county.)

The formations also have different topography. Badland slopes on the Sentinel Butte Formation are steep and minutely rilled, whereas badland slopes on the Tongue River Formation tend to be more gentle, smoother, and more rounded. The contrast is conspicuous along the Missouri bluffs in T. 153 N., R. 93 W.

In general, the badlands in southernmost Mountrail County resemble the dark rugged badlands of the Sentinel Butte Formation along the Little Missouri River from the North Unit of Roosevelt Park eastward to Lake Sakakawea. In contrast, the badlands westward from the mouth of the White Earth River resemble the brighter, less rugged badlands of the Tongue River Formation west of the Little Missouri River in the Medora area.

*Fossils.*—Fossils occur in parts of the Tongue River and Sentinel Butte Formations. For instance, petrified tree stumps occur near the base of the Sentinel Butte Formation in Missouri bluffs in the southern part of the county, in sec. 8, T. 150 N., R. 93 W. Fossil leaves and seeds of land plants are abundant in many of the clay and lignite layers; good specimens occur in the clay layers in the roadcuts just south of the junction along the main road 1½ miles north of New Town (at the north edge of sec. 7, T. 152 N., R. 92 W.). Fossil snail shells can be found in some places; for example, in a roadcut in the middle of SE¼ sec. 14, T. 154 N., R. 94 W., or in the center of the north edge of sec. 30, T. 150 N., R. 92 W. Large fossil clam shells are sometimes found, as in the roadcuts 2 miles west of Belden (southwest corner of sec. 16, T. 154 N., R. 91 W.). Small fossil clam shells have also been found in the previously mentioned roadcut 1½ miles north of New Town. Fossil bones or teeth of mammals, turtles, or crocodiles can also be found.

A few hours spent clambering over any of the badlands areas (shown on map 1) will generally turn up a few fossils.

*Age and origin.*—The sediments in the Tongue River and Sentinel Butte Formations were deposited during the Paleocene Epoch, about 65,000,000 years ago, just after the end of the age of dinosaurs.

The sediments were deposited on a flat, sometimes swampy plain, which was similar to parts of the coastal plains of the present southeastern United States. It sloped from the newly risen Rocky Mountains eastward to the ocean, which covered part of the eastern interior of North America at that time. The sand was deposited as a series of bars in a complex of eastward-flowing rivers and along the shores of large shallow lakes. (Some of the sand was later cemented into sandstone by calcium carbonate that had been dissolved in the groundwater.) The silt and clay settled out of backwaters between the individual river channels during times of flood or were deposited in the offshore parts of lakes. The lignite formed where plant debris accumulated in swamps that were not reached by the silty floodwaters.

## Subsurface formations

Only the formations above the Cannonball Formation are exposed at the surface in Mountrail County. The deeper formations, down to the Precambrian rocks at depths of about 12,000 to 14,000 feet, are known from oil wells. Their general character is given in table 1, and their thicknesses and depths are given in figure 3. These formations generally dip southwestward into the deepest part of the Williston Basin. They are locally upwarped along the western boundary of the county to form the Nesson Anticline.

The formations of the Zuni Sequence are in large part gray mudstone (mostly shale), though sand or sandstone occurs near the top and bottom of the sequence. The sand layers in the Cannonball, Hell Creek, and Fox Hills Formations may be important sources of groundwater in Mountrail County. The sand of the Dakota Group is an important source of groundwater in eastern North Dakota, but the water is of poor quality and lies at depths of about 4500 to 5500 feet in Mountrail County. The Piper Formation, at the base of the Zuni Sequence, is similar to the formations of the underlying Absaroka Sequence.

The formations of the Absaroka Sequence are more varied than those of the Zuni and are commonly red. The sequence is 500 to 1,000 feet thick. Nitrogen gas has been produced from the Minnelusa and Amsden Formations in the Nesson Anticline at the west edge of the county.

Underlying the Absaroka Sequence is nearly 6,000 feet of limestone, dolomite, halite, anhydrite, and mudstone in the Tippecanoe and Kaskaskia Sequences. Oil and gas is produced from the Madison Formation and Duperow Formation in the northwestern two townships of the county. A description of oil and gas production in this area can be found in the North Dakota Geological Survey publications listed at the end of section A *(29)*. The potentially economic deposits of rock salt (halite) and possibly potash (sylvite) in northwestern North Dakota are described in the publication, "Mineral Resources of North Dakota" *(23)*.

The deepest rocks overlying the Precambrian in Mountrail County are sandstone, mudstone, and limestone of the Deadwood Formation.

# CHAPTER 3–HYDROLOGY

The specific details of the hydrology of Mountrail and Burke Counties are described in volume III of Bulletin 55. Only a general regional survey is presented here.

## Groundwater

Groundwater occupies minute pores or fractures in the sediment in Mountrail County. Pores are the open spaces between individual pebbles or sand or silt grains or clay particles. Fractures occur in the harder or more cohesive sediment such as clay or lignite. Vertical fractures are never more than a small fraction of an inch wide, and horizontal fractures are generally closed tight.

Groundwater occurs only beneath the *water-table.* Here the sediment is completely saturated with water, whereas above the water-table much of the pore-space is filled with air.

Beneath the water-table most sediments contain roughly the same amount of water–10 percent to 35 percent to their volume. However, the rate at which water will seep through the sediment–its *permeability*–depends in part on the size of the pore spaces or fractures: groundwater will seep through sand, gravel, or lignite much more readily than through silt or clay. For this reason, a "seam" of water (an aquifer) consists of a highly permeable layer of sand, gravel, or lignite beneath the water-table; the water in the pore spaces or fractures readily seeps into any well that penetrates these sediments. A clay layer penetrated by a well may contain much groundwater in its pore spaces, but its permeability is so low that water seeps into wells very slowly.

The water-table comes to the surface at groundwater *discharge* areas. Many of the natural discharge areas in Mountrail County are indicated on map 1; groundwater discharges into intermittent and perennial lakes and ponds, gaining streams, and springs. Most of this water evaporates or is given off by the more lush vegetation that is characteristic of discharge areas; only a very small percentage of it leaves the county in streams.

The groundwater is replenished or *recharged* by infiltration of precipitation through the surface soil on the upland areas. Essentially all the groundwater within the upper few hundred feet of sediment of Mountrail County originated locally by infiltration into the soil somewhere within the county.

The water-table is commonly at depths of 20 to 50 feet in recharge areas in Mountrail County; it may be as deep as 100 feet in uplands that have good under-drainage through underlying layers of permeable sediment.

The depth of the average low position of the water-table in any area can be approximately determined in drill holes by noting the depth at which the color of the sediment changes from shades of yellow and brown (indicating oxidation of the iron oxides in the sediment) to neutral grays or shades of blue and green (indicating nonoxidation).

The water-table level is controlled by recharge. In dry years, when little water infiltrates into the recharge areas, the water-table drops slightly; in wet years, when there is much infiltration, it rises slightly.

Groundwater seeps through the sediment along irregular paths from the recharge areas to the lowland discharge areas; groundwater movement is generally nearly vertical through materials of low permeability (such as silt and clay) and nearly horizontal through materials of high permeability (such as sand, gravel, and lignite). Flowing wells occur in lowland discharge areas where the groundwater seepage is upward; the water level in wells in these areas rises higher as the wells are drilled deeper. In contrast, in upland recharge areas where groundwater seepage is downward, the water level in wells drops as the wells are drilled deeper.

The chemistry of the groundwater in Mountrail County is largely controlled by its seepage path through the sediment. Near the recharge end of the seepage path the sediment has been largely flushed of the more soluble material, and the groundwater has been in contact with sediment only long enough to dissolve small amounts of mineral material.

As a result, calcium-bicarbonate groundwater with small amounts of total dissolved solids commonly occurs in upland areas where the groundwater has moved (a) slowly through a few hundred feet of poorly permeable silty or clayey sediment or (b) rapidly through a few thousand feet of highly permeable sand or gravel; this water tends to be hard.

Near the discharge end of deep seepage paths, the more soluble material has not yet been flushed out of the sediment, and the groundwater has been in contact with the sediment for a great length of time. As a result, sodium-sulfate groundwater with large amounts of total dissolved solids commonly occurs at great depths and in valley bottoms; this water tends to be soft.

For these reasons, plants with low salt tolerance (such as aspen and willows) occur only around upland discharge areas (such as sloughs and ponds in the northeastern part of the county), and alkaline soils occur in lowland discharge areas.

Groundwater contamination can generally be prevented by determining the local groundwater flow pattern. Industrial wastes or sewage will not contaminate the groundwater if they are dumped in groundwater discharge areas that are permanently moist; such areas are intermittent or perennial ponds or streams that are gaining water from the ground. But contamination of groundwater is likely if wastes are dumped in recharge areas such as dry uplands or temporary streams or sloughs that are losing water by seepage into the ground.

## Lakes and Ponds

Hundreds of lakes and ponds occur in the northeastern half of Mountrail County; only the larger ones are shown on map 1. Most are *intermittent* (have no water standing in them during periods of little rain), but some are *perennial* (always have standing water). In contrast, the sloughs discussed in the description of formation A are *temporary* (contain water only during rainy periods or after the spring thaw).

The water level in intermittent and perennial lakes and ponds is controlled largely by the level of the water-table under the adjacent hillslopes. Although surface runoff from adjacent hillsides during rains and during spring thaw contributes considerable water to the lakes and ponds, the sustaining supply during the rest of the year is from groundwater seepage. That is, intermittent and perennial lakes and ponds are major areas of groundwater discharge. In contrast, the groundwater is recharged by infiltration through the bottoms of temporary sloughs.

For these reasons, the chemical character of the water in lakes and ponds is controlled largely by the chemistry of the groundwater. Ponds at high elevations have fairly fresh water because the groundwater is of local origin. The freshest large lakes in the county are probably Clearwater Lake and Lostwood Lake, the only large lakes above 2200 feet elevation.

In contrast, the lakes at lower elevations are brackish or saline because they are fed by groundwater that has moved much farther and much deeper. Most brackish lakes in Mountrail County are below 2200 feet elevation (fig. 2). Some of these lakes, such as Shell Lake, have outlets; their water is not much more brackish than the groundwater that feeds them. However, most lakes in Mountrail County, such as White Lake, have no outlet; the salts in the groundwater feeding these lakes has been accumulating as long as the lakes have been in existence, for about the past 10,000 years. These lakes are extremely saline. The salt is in large part sodium sulfate.

*Sodium-sulfate lakes.*–Sodium sulfate in commercially usable amounts may be present in some lakes in Mountrail County *(30)*.

The salt lake 2 miles east of Palermo in sec. 7, T. 156 N., R. 89 W., is about 230 acres in area. It is frequently dry, especially during the fall and winter. Its dry surface is covered with a white sodium-sulfate crust 1 or 2 inches thick. Beneath the crust is about 6 inches of mud containing sodium-sulfate crystals. Beneath the mud is a hard, compact layer of nearly pure sodium-sulfate crystals; this layer is 2 to 7 feet thick. Beneath this is another layer of mud containing sodium-sulfate crystals; it is about 5 feet thick. Beneath this is mud without crystals. The layer of nearly pure crystals contains roughly 1,300,000 tons of hydrous sodium sulfate. The entire lake contains about 2,000,000 tons *(30)*.

The salt lake in sec. 21, 22, 27, and 28, T. 157 N., R. 89 W., (250 acres) contains about 600,000 tons of hydrous sodium sulfate. The one in sec. 4, 5, 8, and 9, T. 156 N., R. 89 W., (200 acres) contains about 300,000 tons of sodium sulfate *(30)*.

White Lake, 4 miles northwest of Stanley, is about 2300 acres in area. It contains brine that is as much as 12 feet deep. The brine averages about 10 percent total dissolved solids. (The ocean averages about 3.5 percent.) About 90 percent of the dissolved solids are sodium sulfate. The bed of the lake contains a layer of sodium-sulfate crystals averaging 3 or 4 feet thick. White Lake contains more than 3,000,000 tons of hydrated sodium sulfate *(30)*. Attempts have been made to commercially utilize this material; an evaporation basin has been constructed in section 31 on the south side of the east end of the lake, and the resulting sodium sulfate has been stock-piled at the site.

Other salt lakes in this part of Mountrail County may also contain large amounts of sodium sulfate, but none of them have been evaluated.

A buried layer of sediment deposited in a salt lake has been found in a drill hole (NDSWC test hole 3369) in the southeast corner of sec. 16, T. 157 N., R. 92 W., at the southeast end of Cottonwood Lake. A bed of organic-rich clay containing abundant sodium-sulfate crystals occurs at a depth of about 155 to 175 feet.

### Streams

Two kinds of streams can be distinguished in Mountrail County: gaining and losing. *Gaining streams* gain water by seepage from the groundwater at least part of the year. The sediment beneath the river beds is usually wet or moist and the channels have well defined banks. Thickets of ash, elm, chokecherry, juneberry, buffaloberry, and wild rose grow along many of these streams; marshy areas occur along some of them.

*Losing streams* lose water to the ground. They are temporary and carry water only during spring thaw or rainstorms. The sediment beneath them is often fairly dry. They do not have well defined channels with banks, but rather are merely small V-shaped valley bottoms. Prairie grasses generally grow along these rivers.

Most of the gaining streams in Mountrail County are intermittent; they flow only during wet periods when the water-table is high.

## CHAPTER 4–GEOLOGIC HISTORY

Little is known about Precambrian history in North Dakota. After a long period of erosion the Cambrian ocean rose about 600,000,000 years ago, depositing the shoreline sand and offshore mud and lime of the Deadwood Formation. The sea level then dropped, exposing dry land, which resulted in the erosion of the upper part of the Cambrian sediment (table 1). During Cambrian time the Williston Basin began to sink.

In Ordovician time the ocean again rose, and the shoreline sand of the Black Island Formation was deposited across Mountrail County. Offshore mud was deposited as the ocean deepened. Later, during Ordovician and Silurian times reefs composed of lime deposited by corals and other organisms covered the Williston Basin. At the end of Silurian time the ocean became shallow and the area briefly became dry land, possibly similar to the low-lying limestone terrain of modern Florida.

During Devonian and Mississippian time, from about 400,000,000 to 300,000,000 years ago, limestone reefs were again widespread. As the Williston Basin continued to sink, great landlocked seas formed, and halite and anhydrite were deposited in their highly saline waters. Toward the end of this period, rivers again began to bring in mud from the adjacent continent. The area finally became shallow and again became dry land at the end of Mississippian time.

During the next 150,000,000 years the ocean level fluctuated and the area was alternately dry land and shallow sea as the sediment of the Absaroka Sequence and lower Zuni Sequence were deposited. By Skull Creek time (table 1) the Williston Basin had become a widespread sea into which mud was brought by rivers on the adjacent continent. As the Williston Basin continued to sink, 2500 feet of mud was deposited. At the end of Cretaceous time the sea became shallow and the shoreline sand of the Fox Hills Formation was deposited. Finally the area became dry land as the sea retreated eastward. The last dinosaurs died as the coastal plain sediment of the Hell Creek Formation was deposited. The sea again briefly rose for the last time to deposit the Cannonball Formation. During this time the Nesson Anticline in western Mountrail County was being upwarped and the Rocky Mountains to the west had begun to form. After the Cannonball Sea shrank eastward the coastal plain deposits of the Tongue River, Sentinel Butte, and Golden Valley Formations were deposited. During this time mammals were rapidly evolving and diversifying.

Toward the end of Tertiary time western North Dakota became a rolling upland. The rivers flowing eastward from the Rockies deposited the gravel, sand, and floodplain mud of formations D and E.

During Tertiary time the climate had gradually been changing from tropical to temperate, until in Pleistocene time the ice-age glacier spread across central Canada and reached Mountrail County, one to three million years ago. The rivers that had been flowing northeastward from the Rockies to the present area of Hudson Bay were diverted southeastward around the edge of the ice sheet and into the Mississippi drainage, forming the Missouri River. Several glaciations followed, but little is known about the earlier ones. The last, which began about 22,000 years ago, reached the area of New Town perhaps 15,000 or 16,000 years ago. Before that time the Missouri River had been flowing from the present area of Little Knife Bay and through the valley that contains New Town and Van Hook Arm of Lake Sakakawea. As the glacier advanced into this valley it dammed up the Missouri River, forming a lake that was somewhat larger than that part of modern Lake Sakakawea north and west of Four Bears Bridge. The silt deposited in this lake can now be seen in the shore bluffs ¾ mile north of Four Bears Bridge. The lake soon overflowed the lowest divide south of Four Bears Bridge and quickly cut the modern channel of the Missouri River through that area. This is now the youngest, narrowest, and most rugged part of the Missouri River valley.

About 13,000 years ago the glacier had melted back and was rapidly downwasting. It was covered with tens of feet of pebbly, sandy, silty clay (the material shown in green on map 1 in the pocket in the back of this volume). This material insulated the glacial ice, causing some of it to persist until at least 9,000 or 8,000 years ago. A spruce forest was growing on top of this material; probably little evidence for the buried masses of ice could be seen at that time.

About 12,000 years ago the great North American ice sheet may have melted back far enough that an ice-free area had opened east of the Rocky Mountains in Alberta, permitting big-game hunters to enter from Alaska and Asia. These paleo-Indians quickly spread over the area south of the ice sheet and entered Mountrail County. These early men hunted now-extinct species of horse, mammoths, ground sloth, camel, and bison. All of these, except for the modern species of bison, became extinct about 11,000 years ago, possibly as a result of hunting pressures by these early Indians. Teeth and bones of these animals are occasionally found in North Dakota today.

About 10,000 years ago the climate became somewhat warmer and the spruce forest died out and was replaced by tall-grass prairie. During this time the buried glacial ice had been gradually melting. At first, where the material on top of the ice was the thinnest, and therefore had the least insulating effect, the ice melted out, leaving depressions that were filled with water but surrounded by the buried glacial ice. Silt and clay was deposited in the bottom of these lakes, forming the flat areas shown in blue (silt and clay unit of the Coleharbor Formation) on map 2. These ice-walled-lake plains are agriculturally important areas of Mountrail County because they are free of boulders, are flat, and have fertile, well drained soils. Many of these lake plains, especially those in the Ross area, are surrounded by rims of shoreline sand and gravel (map 1).

Gradually the last of the buried glacial ice melted out, leaving depressions occupied by the modern sloughs and lakes. About 8500 years ago the climate again became drier, probably at least as dry as the driest part of the 1930's. This dry period ended about 4500 years ago when the climate became similar to that of today, but with fluctuations at least as great as during the Dirty Thirties. During the past 10,000 years the sloughs and lakes gradually became shallower due to sedimentation of material eroded from adjacent hillslopes. Erosion was greatest during the drier periods when the sod cover no longer protected the hillslopes.

# NOTES

(Indicated in text by italic number in parentheses)

*(1)* These angles were determined in the field with a clinometer. Generally, the slope angles of several of the steepest slopes visible within several hundred feet of the point of observation were measured and averaged. These determinations were made at a few hundred representative places in the county. They were supplemented by a few thousand field estimations made without the use of a clinometer. Boundaries between the topographic map units were determined on airphoto stereoscopic pairs.

*(2)* The sediment and rock terminology used in this report is shown in figure 6.

*(3)* American Commission on Stratigraphic Nomenclature (1961, art. 4).

*(4)* U. S. Army Corps of Engineers, 1953, The Unified Soil Classification System: Tech. Memo. 3-357.

*(5)* Highway Research Board, 1945, Proceedings of the Twenty-fifth Annual Meeting, v. 25, p. 375-392.

*(6)* The type section of the Coleharbor has been designated as the Dead Man Bluff in sec. 22, T. 147 N., R. 84 W., McLean County, North Dakota. At this location along the east shore of Lake Sakakawea about 3 miles north of Garrison Dam, nearly vertical, wave-cut sections of glacial sediment as much as 70 feet thick occur. The geology of this area has been described in a North Dakota Geological Survey Bulletin by John Bluemle. The Coleharbor Formation contains most of the Pleistocene glacial sediment of North Dakota and adjacent areas. The southern limit of the Coleharbor Formation is the limit of glaciation in South Dakota. Its eastern limit is probably in central Minnesota, where it is replaced by yellower, redder, sandier, noncalcareous, and nonmontmorillonitic glacial sediment. Its southeastern limit is unknown. Its northeastern limit may be near Lake Manitoba, where it is replaced by sandier, much more calcareous, nonmontmorillonitic glacial sediment. Its northern and western limits may be near the Canadian Shield and Rocky Mountains. Except for the material to the southeast, the Coleharbor Formation is largely confined to areas of clay-rich, montmorillonitic Cretaceous and early Tertiary formations in the northern Great Plains. In some areas the Coleharbor Formation can be subdivided on the basis of the characteristics (carbonate

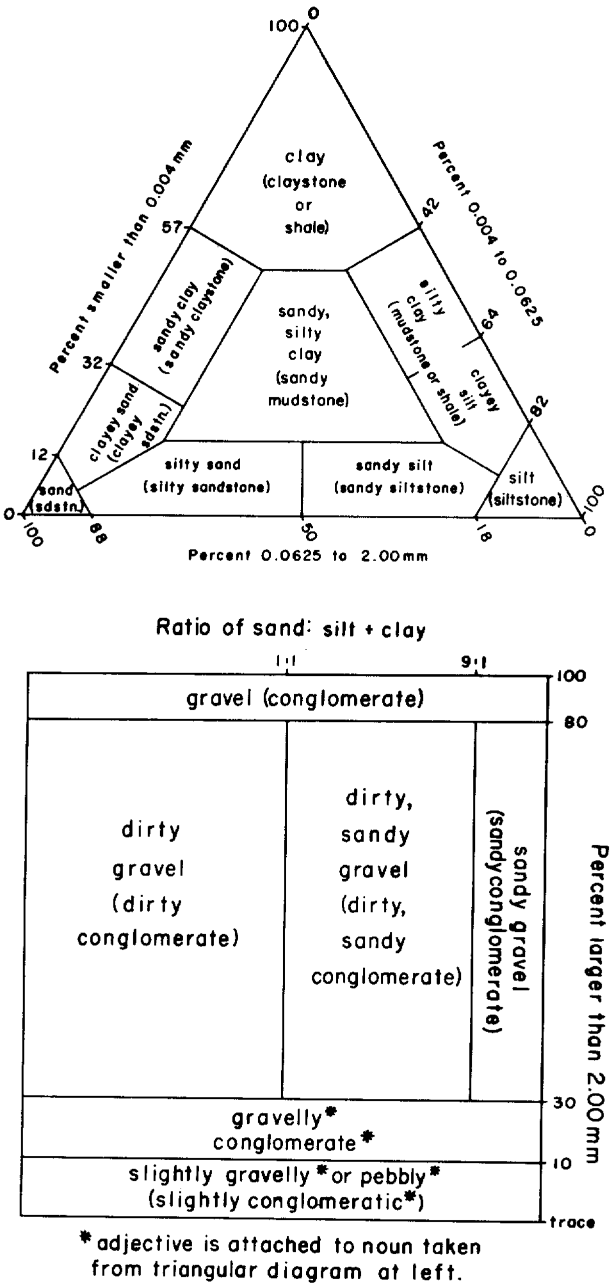

Figure 6.–Sediment (and rock) terminology used in this report.

content, grain-size distribution, etc.) of the pebbly sandy silty clay; for example, the Battleford Member, Floral Member, and Sutherland Member have been named by Christiansen (1968, Canadian Journal of Earth Sciences, v. 5, p. 1167-1173; he, however, gave them the rank of formation or group). Some of the philosophy behind the naming of this new formation is given in section B.

*(7)* The Coleharbor Formation in Mountrail County consists of about (a) 87 percent pebbly, sandy, silty clay, 8 percent sand and gravel, and 5 percent silt and clay, based on surface areas shown in map 1; (b) 85 percent pebbly sandy silty clay, 7 percent sand and gravel, and 8 percent silt and clay, based on 3300 feet of drill logs cited in note *10* (biased slightly in favor of silt and clay) because many of these drill sites are in areas where elevated ice-walled-lake plains are common); or (c) 67 percent pebbly, sandy, silty clay, 18 percent sand and gravel, and 14 percent silt and clay, based on 12,000 feet of drill logs provided by the North Dakota State Water Commission (biased in favor of sand and gravel because of attempts to find aquifers; biased in favor of silt and clay because they commonly occur where aquifers might be expected).

*(8)* The pebbly, sandy, silty clay has the following size composition, based on the averages and standard deviations calculated from analyses of 32 near-surface samples given in the reference cited in note *10*: 33±7 percent less than 0.004 mm,
32±7 percent between 0.004 and 0.064 mm,
31±8 percent between 0.064 and 2 mm, and
4±2 percent greater than 2 mm.

*(9)* Soil Survey Staff, 1951, Soil Survey Manual: U. S. Dept. Agriculture Handbook 18, p. 209.

*(10)* Information on the engineering properties of sediment in Mountrail County comes from reports of subsurface site investigations for the U. S. Air Force, Fourth Deployment area, WS-133A Operational Facilities, Minot Air Force Base, North Dakota (Contact AF 04(647)-807 August 1961 by Porter & O'Brien Consulting Engineers). Laboratory procedures used were in accordance with ICBM Standard Guide of Field and Laboratory Test Procedures prepared by Air Force Ballistic Systems Division. Compressive strength was determined in an undrained triaxial shear test using a consolidation pressure equal to the calculated overburden pressure. Users of this information should be cautioned that some of it is confusing. For example,

the reports for sites 55, 75, 105, 118, 143, 144, 145, and 166 in Mountrail County are all identical except that the plasticity indexes and liquid limits agree with those given on the accompanying grading-analysis report. It should also be noted that the "anticipated" thicknesses of glacial drift greater than 100 feet are generally not based on seismic information.

*(11)* T. M Hamilton, 1970, Groundwater flow in part of the Little Missouri River Basin, North Dakota: Ph.D. dissertation, University of North Dakota, 179 p.

*(12)* In NDSWC test hole 3311, in the southeast corner NE ¼ sec. 20, T. 152 N., R. 92 W., ½ mile southeast of New Town, this body of silt and clay occurs to a depth of 207 feet.

*(13)* NDSWC test hole 3357, NE cor. SE ¼ sec. 34, T. 151 N., R. 92 W.

*(14)* NDSWC test hole 3311 (SE cor. NE ¼ sec. 20, T. 152 N., R. 92 W.; depth 235 to 307 feet), test hole 3473 (SW cor. sec. 3, T. 151 N., R. 92 W.; depth about 109 to 275 ? feet), test hole 3472 (SE cor. sec. 22, T. 151 N., R. 92 W.; depth 119 to 177).

*(15)* NDSWC test hole 3375 (SW cor. sec. 28, T. 157 N., R. 93 W.; depth 70 to 110 feet).

*(16)* NDSWC test hole 3436 (SW cor. sec. 7, T. 153 N., R. 90 W.; depth 89 to 210 feet).

*(17)* NDSWC test hole 3365 (SW ¼ SE¼ NE¼ sec. 20, T. 157 N., R. 89 W.; depth 88 to 163 feet).

*(18)* NDSWC test hole 3357 (NE cor. SE¼ sec. 34, T. 151 N., R. 91 W.; depth 165 feet), test hole 3446 (SE cor. sec. 36, T. 156 N., R. 92 W.; depth 166 to 174 feet), test hole 3347 (SW cor. sec. 23, T. 155 N., R. 92 W.; depth 149 to 154 feet), test hole 3451 (NE cor. sec. 21, T. 157 N., R. 93 W.; depth 69 to 75 feet), and test hole 3452 (SW cor. sec. 2, T. 158 N., R. 93 W.; depth 114 to 119 feet).

*(19)* The Golden Valley Formation has been described by L. J. Hickey, 1966 (The paleobotany and stratigraphy of the Golden Valley Formation in western North Dakota: Ph.D. dissertation, Princeton University, 265 p.). An NDGS auger hole in NE¼ NE¼ sec. 25, T. 154 N., R. 93 W., showed 52 feet of Coleharbor Formation overlying more than 72 feet of the upper member; a bentonite bed is present between depths of 83 and 85 feet. An auger hole in SW¼ NW¼ sec. 32, T. 154 N., R. 92 W., showed 35 feet of Coleharbor Formation overlying more than 60 feet of the upper member; bentonite beds occur at depths of about 38 feet, 44 feet, 54 feet, and 61 to 73 feet. The NDSWC test hole 3372 in

the NW cor. of sec. 10, T. 155 N., R. 93 W., probably also penetrated the upper member at depths of 36 to 60 feet.

*(20)* For instance, the hard siliceous layer occurs 0.2 mile north of the southeast corner of sec. 26, T. 153 N., R. 92 W., and near the southeast corner of sec. 5, T. 152 N., R. 92 W.

*(21)* X-ray determinations by F. R. Karner, Geology Department, University of North Dakota.

*(22)* Great Northern Railway Company Mineral Research and Development Department, 1958, Williston Basin Clays: Rept. 5, 23 p.

*(23)* Oswald Tufte (ed.), 1964, Mineral Resources of North Dakota: North Dakota Economic Development Commission, 126 p.

*(24)* C. F. Royse, Jr., 1967, Tongue River-Sentinel Butte contact in western North Dakota: North Dakota Geological Survey Rept. of Inv. 45, 53 p.; C. F. Royse, Jr., 1967, A stratigraphic and sedimentologic analysis of the Tongue River and Sentinel Butte Formations (Paleocene) western North Daktoa: Ph.D. dissertation, University of North Dakota, 312 p.; and Royse, C. F., Jr., 1970, A sedimentologic analysis of the Tongue River-Sentinel Butte interval (Paleocene) of the Williston Basin, western North Dakota: Sedimentary Geology, v. 4, p. 19-80.

*(25)* Based on a total of 3600 feet of vertical section (a) described by North Dakota Geological Survey geologists in the badlands areas of southern Mountrail County and in auger holes throughout Mountrail County, (b) logged by North Dakota State Water Commission geologists in drill holes throughout the county, and (c) logged in the drill holes described in the reference cited in note *10*.

*(26)* According to C. K. Smith and J. F. Redlinger (1953, Soil properties of Fort Union clay shale: 3rd Internat. Conf. Soil Mechanics and Foundation Eng., Switzerland, Proc., p. 62-66) the Sentinel Butte silt and clay at Garrison Dam is CL or CH; has dry unit weights between 95 and 115 pounds per cubic foot; has natural moisture contents between 16 and 24 percent; has shear strengths ranging from roughly 1 ton per square foot with no load to roughly 6 tons per square foot with a normal load of 10 tons per square foot; had preconsolidation loads between about 80 and 100 tons per square foot (that is, about 2000 feet of overburden might have been eroded away if the sediment never dried out); has coefficient of permeabilities ranging from 0.01 to 0.0001 micrometers per second; may have slopes 100 feet high that are stable at no more than 65 degrees and slopes 200 feet

high stable at no more than 45 degrees; has large amounts of rapid rebound during unloading (but this does not reduce its strength); and has large lateral forces below valley bottoms due to horizontal pressures resulting from former overburden.

*(27)* Q. F. Paulson, 1954, Geology and occurrence of ground water in the Stanley area, Mountrail County, North Dakota: North Dakota State Water Conserv. Comm. Ground-Water Studies 23, 59 p.

*(28)* References on lignite in Mountrail County include (a) R. A. Brant, 1963, Lignite resources of North Dakota: U. S. Geol. Survey Circ. 226, 78 p.; (b) R. J. Dingman and E. D. Gordon, 1954, Geology and ground-water resources of the Fort Berthold Indian Reservation, North Dakota: U. S. Geol. Survey Water-Supply Paper 1259, 114 p.; (c) C. M. Harrer, 1961, Mineral resources and their potential on Indian lands, Fort Berthold Reservation, Dunn, McKenzie, McLean, Mercer, and Mountrail Counties, North Dakota: U. S. Bur. Mines Prelim. Rept. 142, 204 p.; (d) A. G. Leonard, E. J. Babcock, and L. P. Dove, 1925, The lignite deposits of North Dakota: North Dakota Geol. Survey Bull. 4, p. 159-165; (e) M. A. Pishel, 1912, Lignite in the Fort Berthold Indian Reservation, North Dakota, north of the Missouri River: U. S. Geol. Survey Bull. 471, p. 170-186; and (f) C. D. Smith, 1908, The Fort Berthold Indian Reservation lignite field, North Dakota: U. S. Geol. Survey Bull. 381, p. 30-39.

*(29)* C. G. Carlson and S. B. Anderson, 1965, Sedimentary and tectonic history of North Dakota part of the Williston basin: Am. Assoc. Petroleum Geologists Bull., v. 49, p. 1833-1846; C. G. Carlson and S. B. Anderson, 1966, A look at the lower and middle Madison of northwestern North Dakota: North Dakota Geol. Survey Rept. Inv. 43, 14 p.; C. B. Folsom, Jr., 1966, North Dakota crude oil inventory as of January 1, 1966: North Dakota Geol. Survey Misc. Ser. 27.

*(30)* Q. G. Grossman, 1949, The sodium sulphate deposits of western North Dakota: North Dakota Geol. Survey Rept. Inv. 1, 65 p.; E. O. Binyon, 1952, North Dakota sodium sulfate deposits: U. S. Bureau of Mines Rept. Inv. 4880, 41 p.

# SECTION B–LATE CENOZOIC HISTORY OF MOUNTRAIL COUNTY

The environments of deposition of the surface sediments of Mountrail County are shown on map 2 in the pocket at the end of this volume. The late Cenozoic history of Mountrail County and adjacent areas is summarized in figure 9.

## ENVIRONMENTS OF DEPOSITION

### Terminology

The terminology used in this report and on map 2 is somewhat different from the terminology used in previous North Dakota Geological Survey reports, for the following reasons.

The terminology used in naming the sediments of the various depositional environments should not conflict with a basic principle of logic: *genetic* terminology must be independent of *descriptive* terminology unless the origin of the things being named is completely understood (Rodgers, 1950). The various modes and environments of deposition are imperfectly understood (as is most of geology), so two sets of terminology are needed.

*Descriptive* terms, such as those used in section A and on map 1, are relatively unambiguous. A sediment or landform can be described quantitatively or it can be described using terms that are defined quantitatively. Thus, grain-size terms are defined using the Wentworth system.

Similarly, *genetic* terms, such as those used in section B and on map 2, can be unambiguous if they are clearly defined in terms of the exact physical processes involved. Thus, the difference between liquid and plastic behavior can be defined in terms of the different stress-strain relationships.

Several examples will illustrate the problems involved with combined genetic-descriptive terms.

(1) The vague term "ground moraine" may be partly genetic; it has been defined by some geologists as a kind of topography or a body of material or a kind of sediment that was produced by glacial deposition, especially subglacial deposition (however, most "ground

moraine" is probably composed of superglacial sediment). And it may be partly descriptive; it has been defined by some geologists as being flat or undulating, having less than 20 feet of local relief, or lacking transverse topographic lineations. Such a term can be used without confusion only in the most casual situations. A situation where confusion resulted is shown on the *Glacial Map of the United States* (Flint and others, 1959). A 90-mile "borderline fault" occurs between North Dakota and South Dakota. In North Dakota "ground moraine" was separated from "end moraine" on the basis of local relief, whereas the presence or absence of transverse lineations was used in South Dakota. High-relief unlineated topography was called "end moraine" in North Dakota and "ground moraine" in South Dakota, whereas low-relief lineated topography was called "ground moraine" in North Dakota and "end moraine" in South Dakota. This problem might have been prevented if the genetic and descriptive aspects had been clearly separated. Local relief and lineations could have been described consistently and the compilers could then have decided which was the better evidence for the origin being considered.

(2) "Kame" is another word that has little value as a technical term because of the variety of genetic and descriptive implications involved. It seems likely that the "classic cone-shaped kame" is an artifact that developed by the repeated search for, and illustration of, the few cone-shaped hills out of the thousands of "nonclassic" odd-shaped hills that are genetically similar. Most "kames" are probably either (1) the more prominent knobs of eskers that were partly disrupted when they were let down from an englacial or superglacial position, (2) the more prominent hills of a collapsed sheet of superglacial stream sediment, (3) an eroded remnant of stream sediment, or (4) very large boulders (Bluemle, 1970).

(3) The term "end moraine," as commonly used in the Midwest, has lost much of its value. Descriptive characteristics of varying genetic significance (high local relief, ridge-like form) have come to predominate over the genetic aspects of its definition. Thus a ridge-like band of hilly glacial sediment may be called an "end moraine" even if there is evidence that the feature did not accumulate at the edge of a glacier or did not accumulate during an episode of significant change in the regimen of the glacier. Probably "end moraine" should be restricted to the thickening at the outer edge of a drift sheet. Thus, "end moraine" is an interpretation that can be made only *after* the till stratigraphy has been determined (and consequently the definition of a drift unit cannot be based on the presence of an end moraine).

(4) "Dead-ice moraine" has been largely genetic in meaning except for the common stipulation that it must have fairly high local relief (to distinguish it from "ground moraine").

(5) "Esker" might perhaps justifiably have both descriptive (a ridge, or a ridge-shaped body of material) and genetic (formed by a subglacial, englacial, or superglacial stream) implications because the recognition and interpretation of eskers is frequently nonambiguous because bodies of material deposited by subglacial streams, at least, are commonly ridge shaped. However, where englacial or superglacial eskers have been disrupted by the melting of the underlying ice, the individual segments have commonly been called "kames."

(6) The word "till" is another term that has caused confusion because of its dual nature. It clearly has genetic meaning, because material having exactly the same characteristics as North Dakota "till" but resulting from mudflows in Georgia would never be called "till." Some geologists would say that "till" is purely genetic and that its descriptive characteristics should not be included in its definition; that is, "till" can have *any* composition. But this is an example of the common practice of defining a word differently from the way it is used. This can be illustrated by comparing two materials that were deposited exactly the same way. (a) Pebbly, sandy, silty clay was thrust up on top of a glacier and then flowed to its final resting place as the last ice melted. (b) Clay was deposited in a superglacial lake and then flowed to its final resting place as the last ice melted. The first would generally be called "till" ("ablation till" or "flowtill") and the second would be called "mudflow deposits." The first is called "till" because it has descriptive characteristics usually associated with "till," whereas the second does not. It might be argued that the first is called "till" because its previous history is important (it was thrust up from the base of a glacier). Yet the second would not be called "lake sediment," because it is no longer laminated. The first could be called collapsed superglacial glacial sediment or collapsed glacial sediment and the second could be called collapsed superglacial lake sediment or collapsed lake sediment. (Thus it would seem that sediment should be given genetic names based primarily on the last process acting on them; an arkosic sand deposited by a stream should be called "stream sediment," not "granite.") It might also be argued that the first is normally called "mudflow" sediment and that "till" is restricted to glacial sediment that has not undergone any secondary modification such as flowage. This would never receive popular support because at least 90 percent of the material now commonly called "till" in North Dakota has undergone flowage. Similarly, few geologists would call a material "till" if it were composed

solely of clay even if it had all the genetic requirements for a "till." An added complication is that nonglacial material, such as material that falls on top of mountain glaciers, is also commonly called "till." So it is obvious that "till" has both genetic and descriptive elements in its definition and that its usage is confused. Perhaps one cause of this confusion is the lack of a commonly accepted descriptive term for material having about equal parts of sand, silt, and clay, plus a few percent gravel-sized material. "Pebbly, sandy, silty clay," used in this report, and "slightly gravelly, sandy, silty clay" are cumbersome. "Pebbly, sandy mud" and "slightly gravelly, sandy mud" are shorter, but imply wetness to some people. "Pebbly loam" and "slightly gravelly loam" imply a narrower range of grain size to those familiar with the USDA terminology, and they imply organic content to many not familiar with USDA usage. "Boulder-clay" might be defined as any material ranging in size from boulders to clay, but to many geologists it has genetic significance and is equivalent to "till." "Diamicton" is not known by all geologists (it is not in the 1960 AGI *Glossary* ) and is inappropriate in reports used by nongeologists. For these reasons, there has been a tendency to use "till" in a descriptive sense.

So, it is clear that there is a need for genetic terminology that is free from descriptive implication. In most cases the least confusing terms are those that say exactly what is meant in commonly-used English words. Thus "varves," which may mean either yearly layers or rhythmical layers, can be abandoned in favor of the terms "yearly layer" and "rhythmical layer." "Loess," which may mean either windblown silt or a certain kind of silt of various origins, can be abandoned in favor of "windblown silt" (or perhaps "dust") and the descriptive terms needed to describe the other material. Sediment deposited by the direct action of an active glacier (and not subsequently reworked) can be called "glacial sediment," and sediment deposited by a stream can be called "stream sediment."

## Glacial geology

*Subglacial erosion.*–Evidence of subglacial erosion includes polish, scratches, grooves, and furrows on the subglacial surface. Extensive glacial erosion in North Dakota is commonly indicated by long, narrow, longitudinal ridges and furrows a few feet to a few tens of feet high ("fluting" or "long, linear drumlins"). No extensive areas of subglacial erosion were recognized in Mountrail County, though much glacial erosion undoubtedly occurred.

*Subglacial deposition*.–Subglacial material deposited by a moving glacier in areas of parallel or extending flow has been called "lodgment till." Because it is material that is dragged along a shear plane, it is analagous to fault gouge. There is no known evidence for the existence of any large amount of this bedload sediment in North Dakota. On the contrary, exposures of glacial sediment commonly show some evidence of having been let down from a superglacial position; the sediment commonly has inclusions of clay, silt, sand, or gravel that has folded or faulted bedding. However, exposures are generally inadequate and it is impossible in most places to distinguish glacial sediment deposited beneath the ice from that deposited from on top of the ice. For this reason, an attempt was made to identify glacial sediment deposited beneath the ice (map 2) by the absence of topographic features characteristic of superglacial deposits, as outlined in subsequent paragraphs. However, these features may in part be lacking because of postglacial erosion.

*Glacial thrusting and folding*.–The material beneath a glacier is commonly folded or upthrust to form ridges that have been called "end moraines." Examples include the "Streeter Moraine" in the south-central part of the state and the Binford Hills in Griggs County. However, if they are composed of obviously nonglacial material, such as the Sibley Buttes in Kidder County, which are composed of Cretaceous sandstone, they are seldom called "end moraines," and the material is not called "till." Ridges formed by folding or thrusting at the margin of a glacier are seldom the result of a change in glacial regimen and should therefore not be called "end moraines." These ridges are commonly the result of purely local causes, such as subglacial topography that causes compressing flow in the glacier or a buried aquifer that localizes the high uplift pore pressure resulting from the head provided by the glacier, thus reducing the shear strength of material near the edge of the glacier (Moran, 1971; Bluemle, 1970; Hubbert and Rubey, 1959).

*Collapsed glacial sediment*.–The characteristics of collapsed glacial sediment have been summarized by Clayton (1967). The topography of collapsed glacial sediment is dependent on the thickness of the original blanket of superglacial sediment. In general, the present-day local relief is roughly equivalent to the thickness of the superglacial sediment. That is, the sediment was probably a few feet thick where the present-day topography is flat, a few feet to a few tens of feet where the topography is undulating, a few tens of feet to several tens of feet where the topography is rolling, and several tens of feet to about 150 feet where the topography is hilly (map 1). Where the superglacial sediment was more than several tens of feet thick it masked the sinkholes in the stagnant ice and restricted the freedom of action (flowing and sliding) needed to form "doughnuts" ("circular disintegration ridges"); that is, "doughnuts" do not occur in hilly topography.

The topography of collapsed glacial sediment is also dependent on how closely the sediment-bearing shears were spaced. Where they were relatively far apart the glacial sediment occurred in bands on the ice and was let down to form transverse ridges ("washboard moraines" or "minor moraines"), as in much of the Drift Prairie of North Dakota. Where the shears were closely spaced, the glacial sediment coalesced into a continuous blanket on the ice and was let down to form equidimensional forms such as "doughnuts." Where the sediment was more than a few tens of feet thick, the superglacial sediment coalesced into a continuous blanket even over the most widely spaced shears; that is, the transverse ridges seldom occur in areas of rolling or hilly topography. The low transverse ridges in eastern North Dakota are commonly composed, at least in part, of flat-lying lake sediment because of topographic inversion: where the superglacial shear bands were separated by clean ice, the interband areas were less well insulated and melted faster, leaving the shear bands as ice-cored ridges; glacial sediment slumped down the sides of the ridges and lake sediment accumulated in the inter-ridge troughs; and finally the ice cores melted out, leaving ridges of glacial and lake sediment in the former inter-ridge areas.

The topography of collapsed glacial sediment also depended on the fluidity of the sediment during deposition. The more fluid the sediment, the greater the tendency of the shear bands to coalesce and the flatter the resulting topography. Fluidity is related in part to clay content, type of clay minerals present, and moisture content. So transverse ridges are more common in northeastern North Dakota because the glacial sediment there has a low sodium-montmorillonite content because it was derived from the silicous shale of the Odanah Member of the Pierre Formation.

The topography of collapsed glacial sediment is also controlled by the underlying topography if the superglacial blanket is thin enough to incompletely mask the underlying pre-existing topography.

In areas where the accumulation of superglacial sediment was the result of intensified compressing flow that was caused by some local subglacial topographic configuration, the resulting hillier topography has been called "dead-ice moraine." These areas are irregular in outline and bear no specific relationship to any ice-frontal position. An example is the patch of hilly topography between Cottonwood Lake and White Lake.

## Fluvial geology

The character of fluvial deposits and landforms have been summarized by Allen (1965, 1968), McGowen and Garner (1970), Harms and Fahnestock (1965), Simons, Richardson, and Nordin (1965), and Raudkivi (1967).

*Gravel rivers.*–Rivers transporting large amounts of gravel or sandy gravel are commonly highly braided, have rapid (supercritical) flow, and have upper-flow-regime bedforms. As a result, fluvial gravel and sandy gravel deposits are poorly sorted and have crude, nearly flat bedding. Crossbedded sand is uncommon and overbank silt and clay is rare.

Gravel rivers are rare in this area today; they are commonly found in mountainous areas. During late Wisconsinan time, however, a large amount of gravel was washed out of unstable slopes composed of glacial sediment, and the rivers were larger because of the greater precipitation and melting glacial ice. As a result, there are large amounts of upper-flow-regime gravel of late Wisconsinan age in Mountrail County (map 2). Much of it was deposited on top of stagnant glacial ice; it collapsed as the ice melted out and now has rolling or hilly topography with large numbers of sloughs (map 1).

*Sand rivers.*–Rivers transporting sand or gravelly sand commonly meander or are only slightly braided. Unlike highly braided gravel rivers, they have little material in their beds that is near the limit of their competence. For this reason, they are able to assume a meandering path and are able to adjust their channel so that the flow is tranquil (subcritical) and there are lower-flow-regime bedforms most of the time.

As a result, fluvial sand and gravelly sand is conspicuously crossbedded. A typical point-bar sequence becomes finer upward and consists of, from bottom to top, (1) a very thin layer of lag gravel deposited in the deepest part of the channel, (2) a thick layer of dune-crossbedded sand, with some associated flat-bedded upper-flow-regime sand, deposited in the lower part of the scroll bar, (3) a thick layer of ripple crossbedded sand, with some associated flat-bedded upper-flow-regime sand, deposited in the upper part of the scroll bar, (4) a thick layer of overbank silt and clay alternating with beds of ripple-crossbedded or flat-bedded sand, deposited on the floodplain near the channel, and (5) a thick layer of overbank silt and clay and some clay or peat deposited in floodplain ponds.

Unless aggradation takes place very rapidly, the upper part of this sequence is preserved only in the last point-bar deposit in a depositional sequence. The ripple-crossbedded layer (3) is thickest (and dune crossbedding is uncommon) in very fine sand, and the dune-crossbedded layer (2) predominates (ripple crossbedding is absent) in coarse and very coarse sand. Flat-bedded sand is most common (as much as half of the sequence) in fine sand. Overbank sediment makes up less than half of the sequence in low sinuosity rivers but predominates in high-sinuosity rivers.

Fluvial deposits of modern permanent or intermittent rivers such as Shell Creek are predominantly fine grained. These rivers are highly sinuous and have large amounts of overbank sediment and smaller amounts of crossbedded channel sediment in their floodplains.

Late Wisconsin and early Holocene fluvial deposits in the Missouri River terrace southeast of New Town, capping lake sediment in the New Town sag, and at numerous other places throughout the county consist of medium to coarse sand and gravelly sand with prominent dune crossbedding and only minor amounts of overbank sediment. This sediment was for the most part deposited by low-sinuosity rivers that were fed in large part by the greater precipitation at that time, rather than by glacial meltwater.

The sediment of formation D (map 1) probably consists largely of channel and overbank fluvial deposits.

The crossbedded sand in the upper member of the Golden Valley Formation, in the top of the Sentinel Butte Formation, and at various levels in the the Sentinel Butte and Tongue River Formations are probably channel deposits, and some of the associated silt and clay beds are overbank deposits.

*Gravel-mud rivers*.—Meandering rivers and streams flowing through badland areas such as the Little Missouri River and its tributaries and parts of the White Earth River, the Little Knife River, and many smaller streams in Mountrail County have characteristics shared with both gravel rivers and high-sinuosity sand rivers. A typical pointbar sequence consists of, from bottom to top, (1) a thick layer of flat-bedded upper-flow-regime gravel or sandy gravel deposited in the channel bottom and in the lower part of the scroll bar, (2) a moderately thin layer of flat-bedded sand, with some dune crossbedding, deposited on the middle part of the scroll bar, (3) a moderately thick layer of ripple crossbedded sand, with some flat-bedded sand, deposited in the upper part of the scroll bar and on the floodplain, grading upward into (4) a thick layer of overbank sediment.

## Eolian geology

Eolian sediment consists of dune-crossbedded sand or suspended-load silt. Only a small amount of sediment in Mountrail County has been interpreted as eolian. Some of the sand on the uplands south of Shell Creek were probably windblown, though few exposures of the sediment was seen. A blanket of windblown silt, at most a few feet thick, occurs on flat surfaces near Lake Sakakawea, and a few inches of windblown silt occurs at the surface in most parts of the county.

## Shoreline geology

Shoreline deposits can be grouped into the following categories.

(1) Backbeach sediment consists of a solitary, large-scale, high-angle (dipping about 30 degrees), tabular crossbedded set that was deposited by angle-of-repose avalanching of sand or gravel washed over the top of a beach ridge into the backbeach lagoon.

(2) Topbeach sediment consists of a thin layer of flat-bedded, moderately well sorted upper-flow-regime sand or gravel washed across the top of a beach ridge.

(3) Forebeach sediment consists of nearly flat-bedded (dipping less than 10 degrees generally), very well sorted upper-flow-regime sand or gravel deposited between the high-water and low-water marks.

(4) Shallow nearshore sediment consists largely of lower-flow-regime, moderately well sorted sand in small-scale and large-scale, medium to high-angle (dipping about 15 to 30 degrees), grouped, tabular, crossbedded sets that were deposited at the slipface of ripples and bars, below the low-water mark and above the breaker zone.

(5) Deep nearshore sediment consists largely of lower-flow-regime, moderately well sorted sand in small-scale, medium to high angle, grouped, generally tabular, crossbedded sets that were deposited at the slipface of ripples below the breaker zone and above the effective wave depth.

In areas where water is rising relative to the land, the complete deposition sequence consists of, from bottom to top, lagoonal, backbeach, topbeach, forebeach, shallow nearshore, deep nearshore, and offshore sediment. In areas where a delta is being built out into a body of water, the complete depositional sequence consists of, from bottom to top, offshore, deep nearshore, shallow nearshore, forebeach, and various fluvial, eolian, and lacustrine sediments.

Shoreline deposits in Mountrail County include gravel, sandy gravel, and gravelly sand deposits around large modern lakes and around late Wisconsinan ice-walled-lake plains, especially the low-level ones in the Ross area (maps 1 and 2); these have been described by Clayton and Cherry (1967).

Widespread persistent beds of shoreline sand occur in the Tongue River and Sentinel Butte Formations and possibly in the upper member of the Golden Valley Formation.

## Offshore geology

Offshore deposits consist largely of turbidity-current sediment deposited below the effective wave depth, though pelagic fallout may be locally common.

The silt and clay of late Wisconsinan lake plains in Mountrail County are almost entirely suspended-load sediment deposited by continuous turbidity currents originating where the turbid and commonly cold (and therefore heavy) river water flowed beneath the relatively clearer and less dense lake water. Because turbidity currents flow to the lowest part of a lake basin the lowest areas are filled with sediment first, resulting in a very flat lake bed. That is, the flatness of lake plains is an indication of the presence of turbidity-current deposits, because sediment deposited from other turbid currents would be rather evenly draped over the lake-bottom topography.

The Crow Flies High silt (discussed in subsequent paragraphs) is rhythmically bedded, and each bed coarsens downward. This silt may have been deposited by discontinuous turbidity currents caused by slumping on the face of the delta to the north where a melt-water river in the Little Knife valley flowed into the proglacial lake in the Missouri valley; that is, each bed might represent a single slump and turbidity current. Alternatively, this may be a continuous turbidity current deposit and each bed may be a yearly layer.

Probably much of the silt and clay in the Tongue River, Sentinel Butte, and perhaps the Golden Valley Formations is suspended-load deposits of lacustrine offshore turbidity currents. Much of the irregularly laminated silt and clay was deposited by continuous turbidity currents, but some is rhythmically bedded (such as in the Tongue River Formation in sec. 13, T. 153 N., R. 95 W., in Williams County) and so are either a yearly deposit or are the result of discontinuous turbidity currents.

## Hillslope geology

Hillslope processes include sheet wash, particle creep, eolian activity, falling, sliding, plastic flow, liquid flow, and solution by subsurface water. These processes are responsible for shaping the topography in the areas that are free of glacial landforms, such as the areas of erosional topography shown in red on map 2, and have considerably modified the glacial landforms since glaciation. In glacial landscape, where the drainable is nonintegrated, the solid products of these hillslope processes accumulate in the sloughs and lakes. In other areas they are carried away by the rivers. The rivers of Mountrail County dump several tens of thousands of tons of suspended sediment into Lake Sakakawea every year. Measurements by the U. S. Geological Survey show that these rivers discharge a roughly equivalent amount of dissolved and suspended material, indicating that solution is one of the most important erosional processes in the area. These hillslope processes together lower the landscape of Mountrail County an average of about 0.001 inch a year.

The two most obvious and widespread slope processes are slopewash and particle creep. In badland areas, slopewash is about 1000 times more important than creep; it erodes the hillslopes about 0.1 inch a year (Tinker, 1970). The products of slopewash and creep accumulate at the base of hillslopes. These deposits grade laterally into slough sediment in areas of nonintegrated drainage and into fluvial deposits in valley bottoms in areas of integrated drainage.

Landslides and plastic flows are common only in the areas of badlands or hilly topography, along the White Earth River, the lower Little Knife River, and the breaks bordering Lake Sakakawea.

Deep-seated plastic flow of sediment, possibly extending to depths of hundreds of feet, is responsible for the very slow movement of very large amounts of material into valley bottoms, where the rivers carry it away. This movement results in draping of the overlying sediment to form synclines along most valleys in western North Dakota. (These synclines have commonly been thought to have pre-existed the valleys and to be of "tectonic" origin, and it has been thought that the rivers somehow sought out the synclines, but there are no significant accompanying differences in lithology or jointing that could have had any influence on the location of the rivers.)

Eolian hillslope erosion has probably been rather minor in Mountrail County during the Holocene, although some significant eolian erosion may have taken place locally in mid-Holocene time.

The period of greatest hillslope activity for which there is widespread evidence in Mountrail County was during late Wisconsinan and earliest Holocene time. Water-logged superglacial sediment underwent extensive slumping and flowing as the underlying ice melted.

## GLACIAL STRATIGRAPHY

*Terminology*.–The great bulk of the glacial deposits in North Dakota are included in the Coleharbor Formation, which was described in section A. Rock-stratigraphic (lithostratigraphic) units (formations) are based on observable physical properties; they are the practical descriptive stratigraphic units. Most of the Pleistocene pebbly, sandy, silty clay in North Dakota has not yet been subdivided by gross physical properties into separate formations. The two other main facies–sand and gravel, and silt and clay–are complexly interbedded and interlensed with the pebbly, sandy, silty clay. No practical purpose would now be served by giving formal names to most of these individual beds and lenses. The formal naming of the Coleharbor Formation is justifiable because it is a distinctive and uniform rock-stratigraphic unit consisting of numerous alternating beds of the three main facies that together form a more uniform and more distinctive unit than most of the other previously named surface formations in the state. As can be seen in section A, the formal naming of the Coleharbor Formation is also practically necessary in purely descriptive rock-stratigraphic discussions. It could have been informally called "formation C," but only confusion could result when comparisons are made with other counties where it might be called "formation B" or "formation E." (Formations A, B, D, and E were not formally named because they have not yet been well enough studied to be adequately characterized).

However, for interpretative or historical purposes, another kind of stratigraphic terminology is needed. The great value of rock-stratigraphic units as practical descriptive units rests in part on the restriction that inferred geologic history can have nothing to do with their definition. Units based on inferred geologic history can be called event-stratigraphic units (or ecostratigraphic units, according to Krumbein and Sloss, 1963, p. 51). Glacial event-stratigraphic units in Mountrail County include the Dead Man (?) Drift, the Napoleon (?) Drift, and the Lostwood Drift, described below. All three consist of drifts that have similar gross physical properties; their differentiation is instead based on rather complex historical interpretations of the sequence of glacial events in Mountrail County. Because event-stratigraphic units are interpretive, their persistence as formal terms may be rather ephemeral because interpretations change as more knowledge is gained, whereas properly-defined rock-stratigraphic names should be relatively permanent because they are based on unchanging physical properties.

For these same reasons, descriptive lithologic terms such as "pebbly, sandy, silty clay," "sandy gravel," or "clayey silt" are used when describing rock-stratigraphic units, whereas genetic lithologic terms such as "glacial sediment," "stream sediment," or "lake sediment" are used when discussing event-stratigraphic units. That is, "Ajax Till" or "Ajax Drift" could not be considered proper designations for formations or other rock-stratigraphic units; they are event-stratigraphic designations.

Event-stratigraphic units and their corresponding geologic-event (ecochronologic) units in North Dakota have been discussed in North Dakota Geological Survey Report of Investigation 44 and will be described in detail in a report now in preparation.

The three basic types of stratigraphic units can be summarized as follows.

1. Rock-stratigraphic (lithostratigraphic) units are the basic geologic mapping units. They are defined on the basis of observable descriptive lithologic properties and stratigraphic position. Interpreted age or origin plays no part in their definition. The units are called sequences, groups, formations, members, and beds.

2a. Geologic-time (geochronologic) units have time-parallel boundaries, which may be arbitrarily, but conveniently, chosen. The units are called eras, periods, epochs, and ages.

2b. Time-stratigraphic (chronostratigraphic) units consist of the material deposited during geologic-time units. Units are called systems, series, and stages.

3a. Geologic-event (ecochronologic) units may have time-transgressive boundaries, which are interpretive, rather than arbitrary. Thus, the Lostwood Glaciation may be interpreted as having ended about 15,000 B.P. in central North Dakota and about 12,500 B.P. in northeastern North Dakota, whereas the Wisconsinan Age may be defined to have ended everywhere at 10,000 B.P. Geologic-event units are interpretive episodes during which any kind of specified geologic event took place at any locality. ("Geologic-climate" units are a particular kind of geologic-event unit.) Units are called phases, glaciations, stades, marine transgressions, orogenies, pedogenic episodes, pluvial episodes, droughts, floods, aggradational episodes, stability episodes, etc.

3b. Event-stratigraphic (ecostratigraphic) units consist of the material deposited as the result of a geologic event; thus, the Lostwood Drift was deposited during the Lostwood Glaciation. They differ from rock-stratigraphic units in being interpretive, rather than descriptive; event-stratigraphic units are defined on the basis of a mental concept rather than on the basis of a type section. ("Morphostratigraphic" and "soil-stratigraphic" units are particular kinds of event-stratigraphic units.) Units are called drifts, trangresssional deposits, orogenic deposits, paleosols, pluvial deposits, drought deposits, diluviums, alluviums, stability-surface deposits, etc.

*Dead Man (?) Drift.*–A drift underlying the Lostwood Drift and presumably also underlying the Napoleon (?) Drift in southwestern Mountrail County is very tentatively correlated with the Dead Man Drift in McLean County (Bluemle, 1971). It has been observed at the following localities:

0.3 mi W of SE cor. sec. 9, T. 153 N., R. 92 W.
0.2 mi N of center sec. 11, T. 153 N., R. 92 W.
0.3 mi E of SW cor. sec. 14, T. 153 N., R. 92 W.
0.3 mi W of NE cor. sec. 22, T. 153 N., R. 92 W.
0.3 mi S of NW cor. sec. 7, T. 154 N., R. 92 W.
0.5 mi W of NE cor. sec. 9, T. 154 N., R. 92 W.
0.4 mi W of SE cor. sec. 10, T. 154 N., R. 92 W.
SW¼ SW¼ SE¼ sec. 15, T. 154 N., R. 92 W.
NW of center sec. 11, T. 152 N., R. 93 W.
SE¼ NW¼ NW¼ sec. 6, T. 153 N., R. 93 W.
0.5 mi S of NW cor. sec. 14, T. 153 N., R. 93 W.
SE¼ NE¼ SE¼ sec. 36, T. 154 N., R. 93 W.

At all these localities the Dead Man (?) Drift is separated from the overlying drift by a sharp erosional surface. No soil profile was observed on the Dead Man (?) Drift.

In Mountrail County the drift is distinguished from the Lostwood and Napoleon (?) Drifts by postdepositional weathering characteristics. Above the water-table the till has conspicuous irregular or straight joints that are bordered by zones of iron-oxide and manganese-oxide staining 1 or 2 inches wide; these are absent in the younger drifts. Where outcropping, the Dead Man (?) Drift is generally yellower or redder and more compact than the overlying drifts. It seems also to be somewhat more clayey and have more lignite fragments than the younger tills. The drift is at least 30 feet thick in some areas.

The reddish outwash conglomerate discussed in a previous section on sand and gravel in the Coleharbor Formation may also be part of the Dead Man (?) Drift. It is best exposed in the Sakakawea shore bluffs 1 mile northwest of the Four Bears Bridge.

The age of the Dead Man (?) Drift is unknown. But because it is much more highly weathered than the Napoleon (?) Drift, which might be early Wisconsinan in age, the Dead Man (?) Drift may be pre-Wisconsinan.

*Napoleon (?) Drift.*–The Napoleon (?) Drift is the surface drift over most of the peninsula west of Van Hook Bay as far east as Muskrat Lake and at least as far north as Sanish; it includes all the surface glacial sediment beyond the Lostwood Drift limit. Its topography differs from that of the Lostwood Drift in having almost completely integrated drainage. Collapse topography with a few small sloughs remains only on slightly eroded uplands (undulating topography with nonintegrated drainage on map 1) such as in sec. 32 and 33, T. 151 N., R. 93 W., and sec. 6, T. 150 N., R. 92 W. Erosion has removed collapse topography from the flanks of the upland (rolling topography with integrated drainage on map 1), but erosion has not been great enough to remove all of the drift sheet except at springs and along the steepest bluffs (hilly or badlands topography with integrated drainage on map 1). The topography of the undulating and rolling areas is essentially the preglacial topography that has been modified only in detail by a thin blanket of Napoleon (?) Drift.

The Lostwood and Napoleon (?) Drifts have not been differentiated lithologically. As shown in figure 1 of Clayton (1966), the Napoleon (?) Drift is tentatively correlated with the type Napoleon Drift in southern North Dakota. Its age is guessed to be early Wisconsinan, though a seemingly anomalous radiocarbon date of 11,220±300 (W-402) from northwestern Mercer County may be from drift that is equivalent to the Napoleon (?) Drift.

*Lostwood Drift.*–The Lostwood Drift is the surface drift over most of Mountrail County (map 2). The Lostwood glacial limit is obvious on the peninsula west of Van Hook Bay; there it coincides with the conspicuous contact between the hummocky, slightly eroded collapse topography on the east and the more highly eroded nonglacial topography of the Napoleon (?) Drift on the west. The Lostwood Drift is thicker and more hummocky between the Lostwood glacial limit and Van Hook Bay than in most of the area immediately to the north and east. Muskrat Lake is dammed in an eastward-sloping valley by Lostwood Drift.

Northeast of New Town the Lostwood Drift is draped over the bluffs along the north side of the New Town sag. Bluffs of exposed Sentinel Butte Formation occur only to the west of the Lostwood glacial limit, where the Napoleon (?) Drift has been eroded away; east of the Lostwood glacial limit the bluffs have hummocky collapse topography, and bedrock exposures are generally lacking.

North of the New Town sag the position of the Lostwood glacial limit is more obscure. Tentative correlation with the Charlson glacial limit in McKenzie County (Clayton, 1966, fig. 1) is based in part on the similarities between the topography. Both the Lostwood and Charlson end moraines are bands of relatively slightly eroded collapse topography about 2 miles wide. Behind (north of) both moraines, as far as the Missouri Coteau, are large areas of nonglacial topography where the originally thin drift has been entirely eroded away.

The position of the Lostwood glacial limit north of New Town, as shown on map 2, is also based in part on interpretations related to the Crow Flies High lake sediment.

*Lake Crow Flies High and the Missouri diversion.*--The Crow Flies High sediment (fig. 7) is part of the silt and clay facies of the Coleharbor Formation. It is sediment deposited in a lake dammed in the New Town sag by glacial ice. The apparent absence of Crow Flies High sediment downstream from the Four Bears Bridge suggests that this ice was the same ice that originally dammed the Missouri River here, forcing it from its previous path through the New Town sag to its present path south of the Four Bears Bridge.

Evidence that the Lostwood glacial advance was the same advance that was responsible for Lake Crow Flies High and caused the diversion of the Missouri south of Four Bears Bridge is as follows. Crow Flies High lake sediment occurs up to an elevation of nearly 2000 feet, or about 150 feet above Lake Sakakawea, and it extends at least 50 feet below lake level (NDSWC test hole 3311). The sediment is capped by fluvial sand at an elevation of about 2000 feet in sec. 1 and 12, T. 152 N., R. 93 W., and sec. 7 and the southwest part of sec. 6, T. 152 N., R. 92 W. (Osborn Township). This sand will for convenience be here called the Osborn fluvial sediment. Its upper surface is the original uneroded floodplain surface, but, as can be seen in figure 7 and map 1 and 2, it has been eroded from much of the area, exposing the underlying Crow Flies High silt. Neither this silt, nor the Osborn sand, have been overridden by a glacier. Behind the presumed Lostwood glacial limit east of New Town and west of Little Knife Bay (fig. 7 and map 2) collapsed glacial sediment with numerous sloughs (rolling topography with nonintegrated drainage on map 1) extends down well below the

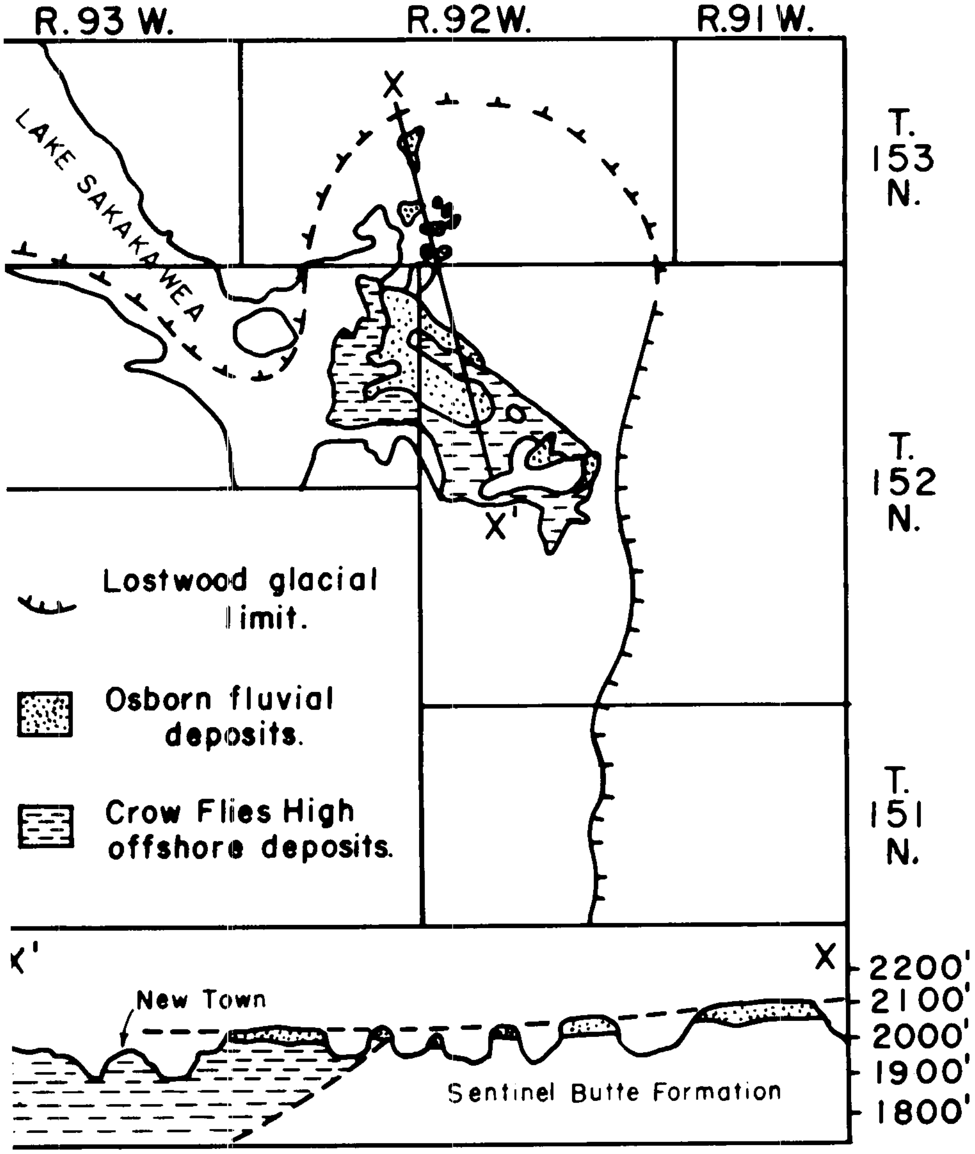

Figure 7.–Distribution of the Osborn and Crow Flies High sediment in the New Town area.

level of Lake Sakakawea, indicating that this glacial sediment was never covered by Lake Crow Flies High or the Osborn rivers. Therefore this Lostwood glacial sediment could not be older than the Crow Flies High sediment or Osborn sediment. If the glacial sediment were a great deal younger, the Crow Flies High and Osborn sediments would have to have been eroded from behind the Lostwood glacial limit (because none now occurs there) but not from in front of it, and after this erosion, the Lostwood ice would have to have advanced almost exactly to these erosion limits; this would seem to be a highly improbable coincidence. Therefore the Lostwood advance must have been nearly contemporaneous with the deposition of the Crow Flies High and Osborn sediments; these sediments do not cover the adjacent lower-level glacial sediment because it was then at a higher elevation on top of the glacial ice enclosing Lake Crow Flies High and the slightly later Osborn rivers. The Crow Flies High lake silt and Osborn sand are therefore part of the Lostwood Drift. The present Missouri trench south of Four Bears Bridge must have formed as soon as Lake Crow Flies High overtopped the lowest divide to the south, which was below about 2120 feet, the approximate highest elevation of the Lostwood limit (2 miles north of Muskrat Lake), and above about 2000 feet, the elevation of the Osborn sand. The divide was probably at the northwest corner of T. 150 N., R. 93 W., the narrowest part of the present Missouri trench. The lake probably filled fairly rapidly and the trench was probably cut rapidly through the soft Fort Union sediments. Therefore the Osborn sediments might have been deposited slightly before the ice reached its outermost limit. After diversion, the Crow Flies High and Osborn sediments were rapidly eroded by Lostwood melt water and the lower-level fluvial sediment south and east of New Town was deposited in front of the Lostwood glacial limit.

*Little Knife interlobe area.*—Crow Flies High sediments coarsen northward in the bluffs along the east side of Little Knife Bay. Apparently the sediment came out of the area between the two lobes of Lostwood ice. A sandy delta (?) facies is present in NW¼ sec. 1, T. 152 N., R. 93 W., and a gravelly sand or sandy gravel outwash facies occurs as high terrace remnants in section 33 and 28, T. 153 N., R. 92 W. (fig. 7). The terrace remnant in E½ NW¼ sec. 28, T. 153 N., R. 92 W., is at about 2050 elevation. These terraces appear to grade downward to the south to the level of the top of the Crow Flies High silt or the level of the Osborn sand. The gradient projects upward into the sky northward of the northernmost terrace remnant in sec. 28 (cross-section in fig. 7); its source here must have been on glacial ice. A half mile to the northeast is an area of hilly collapse topography with nonintegrated drainage; the glacial sediment there must be of Lostwood age. Thus, because the high terraces in sec. 28 and 33 were probably contemporaneous with the Crow Flies High and Osborn sediments, the Lostwood ice limit is shown looped around through the south half of sec. 21 in figure 7 and map 2.

The cause of this interlobate situation was the high elevations (fig. 2) in T. 154 and 153 N., R. 92 W., which are the areas underlain by the Golden Valley Formation (fig. 5). The Little Knife River flows through the center of this area in a gorge that is 400 feet deep. The upper Little Knife once flowed northeastward from near a divide in approximately sec. 32, T. 154 N., R. 92 W., but was diverted southwestward by glacial damming of the once northeastward-sloping valley. However, the diversion would have instead been through lower areas to the southeast or northwest if these areas had not been occupied by ice at the same time; that is, this area was an interlobe area when the Little Knife gorge was cut. There is no evidence that the area was glaciated after the gorge was cut. Therefore, the Little Knife gorge was probably cut by melt water flowing southwestward from an interlobate area during the last glaciation–during the Lostwood advance.

*Extent and age of Lostwood Drift.*–All of the surface drift from the Lostwood glacial limit northward across the Coteau to the Missouri Escarpment is considered part of the Lostwood Drift. This is contrary to most previous interpretations; the more highly eroded southern part of this drift sheet (especially that in southern Williams County and northern McKenzie County) are generally considered to be much older than the less eroded drift of the Missouri Coteau. All of the Lostwood Drift in Mountrail County is thought to be nearly contemporaneous, however, because after the last active ice was gone from the Coteau a continuous sheet of buried stagnant ice remained between the Missouri Escarpment and the Lostwood glacial limit, a distance of about 40 miles. Evidence for this is the nearly continuous interlocking disintegration ridges, collapsed superglacial fluvial sediment, and ice-walled-lake plains throughout this area; this is possible only with a nearly continuous sheet of stagnant ice. The stagnant ice should have taken no more than a few thousand years to melt. The Lostwood advance should therefore have been at its outermost position at most a few thousand years before the last active ice disappeared from the northeast part of Mountrail County about 13,000 years ago. Therefore the outermost Lostwood Drift should be no older than about 16,000 years, and the Missouri River may have been diverted to its present position between Four Bears Bridge and Van Hook Bay no more than a few hundred years before that.

During the Lostwood Glaciation there may have been some minor shifts in the glacial regime. Evidence for this is the ice-frontal positions to the east that are marked by evidence of slight readvances between about 13,000 and 14,000 years ago; they are the Martin, Cooperstown, Luverne, Grace City, Kensal, Streeter, and Burnstad ice-frontal positions. The Martin ice-frontal position has been correlated westward through Ward County by Pettyjohn (in preparation); in Mountrail County it marks approximately the boundary between hilly collapse topography and rolling collapse topography southeast of the Lostwood Lakes (map 1). The Ryder ice-frontal position recognized in Ward County by Pettyjohn corresponds to the boundary between rolling and undulating collapse topography in Mountrail County. The location of Pettyjohn's Makoti ice-frontal position is obscure in Mountrail County. The Martin, Ryder, and Makoti represent, at most, only slight shifts in regime of the Lostwood glacier.

To the east, the Lostwood ice-frontal position probably correlates with Blue Mountain ice-frontal position as shown in figure 1 of Clayton (1966). Pettyjohn (1967) considers the Blue Mountain drift to be considerably older (early Wisconsin, perhaps) than the Makoti drift (about 13,000 years old) because he believes that the oxidized zone on top of the Blue Mountain drift is present beneath the Makoti drift because only one oxidized zone occurs on drift in front of the Makoti ice-frontal position, whereas two (one buried) occur behind it. However, because the drift between the Makoti and Blue Mountain ice-frontal positions is oxidized throughout its thickness, two superimposed zones of oxidation may be present here. This is likely because the surface oxidized zone here is as thick as 45 feet, whereas the buried oxidized zone behind the Makoti ice-marginal position averages 25 feet in thickness, according to Pettyjohn (1967). Because the thickness of oxidized zones is controlled by the lowest position of the water-table, rather than by time, Pettyjohn's Blue Mountain oxidized zone should be no thicker where it is at the surface than where it is buried because the post-Makoti oxidized zone is on an average thinner (20 feet according to Pettyjohn, 1967) than the buried oxidized zone (25 feet), indicating that Pettyjohn's post-Makoti water-tables were no lower than his Blue Mountain water-tables.

*Depth of oxidation and water-tables.*—As shown in figure 8, depths of oxidation (reddish and yellowish hues rather than greenish or bluish gray hues) in Lostwood Drift average at least 15 feet greater than depths to present water-table. This suggests that water-tables were at least 15 feet lower sometime within the last 13,000 years—presumably during the middle Holocene dry period.

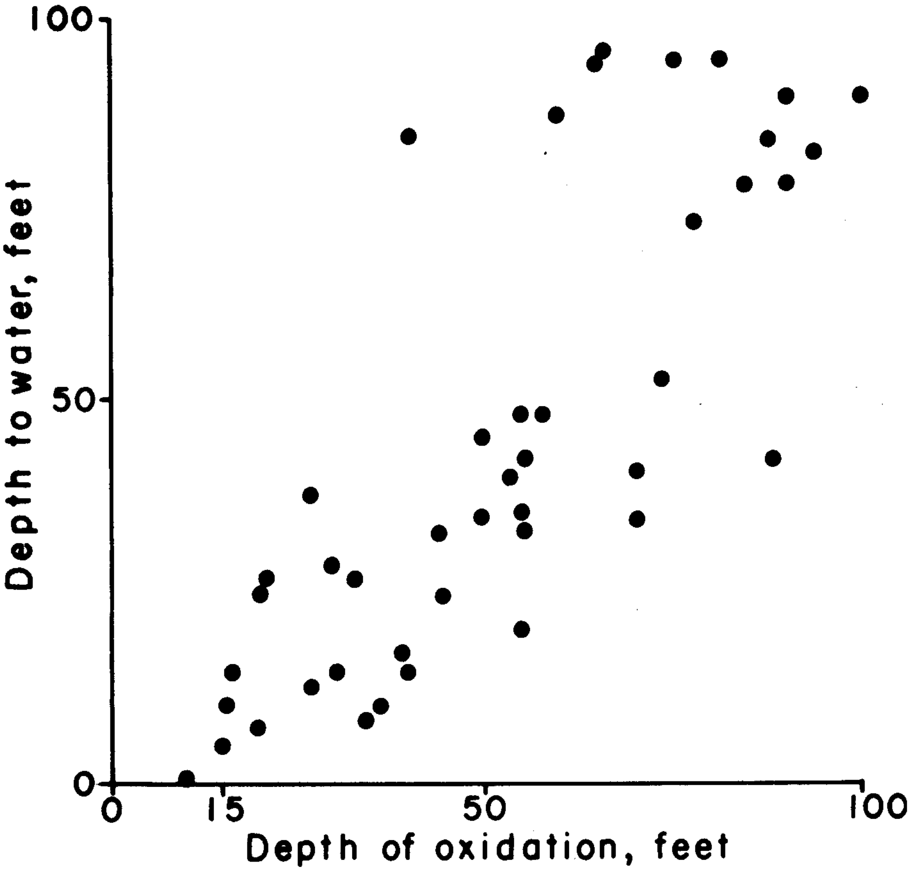

Figure 8.–Relationship between the depth of oxidation and the depth to water in shallow uncased test wells at 43 sites in groundwater recharge areas throughout Mountrail County (see note *10* at end of section A). Several of the water levels are below the base of oxidation, probably because recovery time was not great enough to allow water levels to return to near the water-table position.

*Drift thickness and drainage integration.*–The degree of drainage integration is often used as an indicator of drift age. It is obvious, however, that drainage integration in northwestern North Dakota was controlled largely by the drift thickness and subdrift topography.

On the Missouri Coteau, where the Lostwood Drift is at least several tens of feet thick, the drainage is completely nonintegrated, with numerous lakes and sloughs. In contrast, the drainage on the Coteau Slope, where the Lostwood Drift is only a few tens of feet thick, is largely integrated where subdrift topography is steep, though it is largely nonintegrated where the subdrift topography is nearly flat, as in southeastern Mountrail County. In southern Williams County and northern McKenzie County where the Lostwood Drift is very thin or lacking and where the subdrift topography is very steep the drainage is completely integrated; the topography is largely nonglacial. To the south of this area the drift is again thick in the Charlson end moraine, where the drainage is largely nonintegrated.

On the thin Napoleon (?) Drift the drainage is completely integrated except in level drainage-divide areas, such as the divide area formerly called the "Krem moraine" in northern Mercer County.

For these reasons, it can be seen that drainage integration must be used with great caution as an indicator of drift age.

*Drift border identification.*–As has been pointed out by White (1962) and Moran (1971) the identification of drift borders or "end moraines" is sometimes difficult. Many of the classic "end moraines" of the lower Midwest are in fact partly buried pre-existing features (the uppermost drift sheet does not thicken to produce these moraine-like forms), and many are related to buried aquifers, not ice-margin positions. Similarly, the "Beldon moraine" and "White Earth moraine" of Colton and others (1963) are not end moraines.

The "Beldon moraine" is the band of hilly collapse topography southwest of Shell Lake (map 1). It is clearly not an end moraine of the Lostwood Glaciation (though it may be a buried end moraine of some earlier glaciation): the direction of last ice movement was parallel to, rather than perpendicular to, this band of hilly topography.

The "White Earth moraine" consists of the bands of hilly collapse topography on the west side of the White Earth River trench and at the top of the Missouri bluffs between the White Earth River and Little Knife River. It is not an end moraine of the last glacial advance: the last glaciation resulted in a continuous sheet of stagnant ice throughout this area, as indicated by the presence of stagnation features in the "moraine" and on either side of it and the lack of meltwater channels or noncollapsed outwash in front of it.

Thus, much more evidence is needed to identify an end moraine or a significant ice-frontal position than the mere presence of a band of hilly topography.

## POSTGLACIAL EROSION

Changes in the rates of postglacial erosion and deposition were controlled largely by climatic changes (fig. 9). Three of the climatically controlled factors that have a dominant influence on the erosional history are (1) amount of hillslope vegetation, (2) amount of hillslope runoff and stream discharge, and (3) elevation of the water-table.

(1) As shown by Hamilton (1967), hillslope erosion in western North Dakota during postglacial time was in part controlled by the plant cover. Erosion was greatest during dry periods and least during wet periods when vegetation stabilized the slopes. This is in agreement with the interpretations of Schumm (1965), who suggested that an increase in hillslope erosion would result during a change from a moist, cool postglacial climate (13,000 to 10,000 B.P.) to a dry, warm mid Holocene climate (8,500 to 4,500 B.P.) in areas such as northwestern North Dakota.

(2) Schumm (1965, p. 787) suggested that these climatic changes would result in about 5 inches mean annual runoff during late Wisconsinan times and about 1/5 inch during mid Holocene time, as compared to about 1 inch at present. As pointed out by Dury (1964) this greater late Wisconsinan runoff is the reason many modern streams are underfit within channels that have meander radii 5 times larger than modern rivers. This is substantiated in Mountrail County. Streams leading away from nearly inactive spring pits in southern Mountrail County are underfit by a factor of about 5.

(3) Stream-channel erosion in large part consists of bank caving, which is largely controlled by groundwater movement through the bank sediment: gaining streams have vertical banks that are actively being eroded whereas losing streams lack banks and do little erosion. For this reason the climate, which controls the level of the water-table, influences the relative proportion of each stream that is gaining or losing, and it influences the intensity of erosion in gaining reaches.

Some possible interactions between groundwater movement, bank carving and other kinds of mass movement, mud seals in the bed of losing streams (Harrison and Clayton, 1970), and fluvial deposition and erosion is suggested in the next two paragraphs.

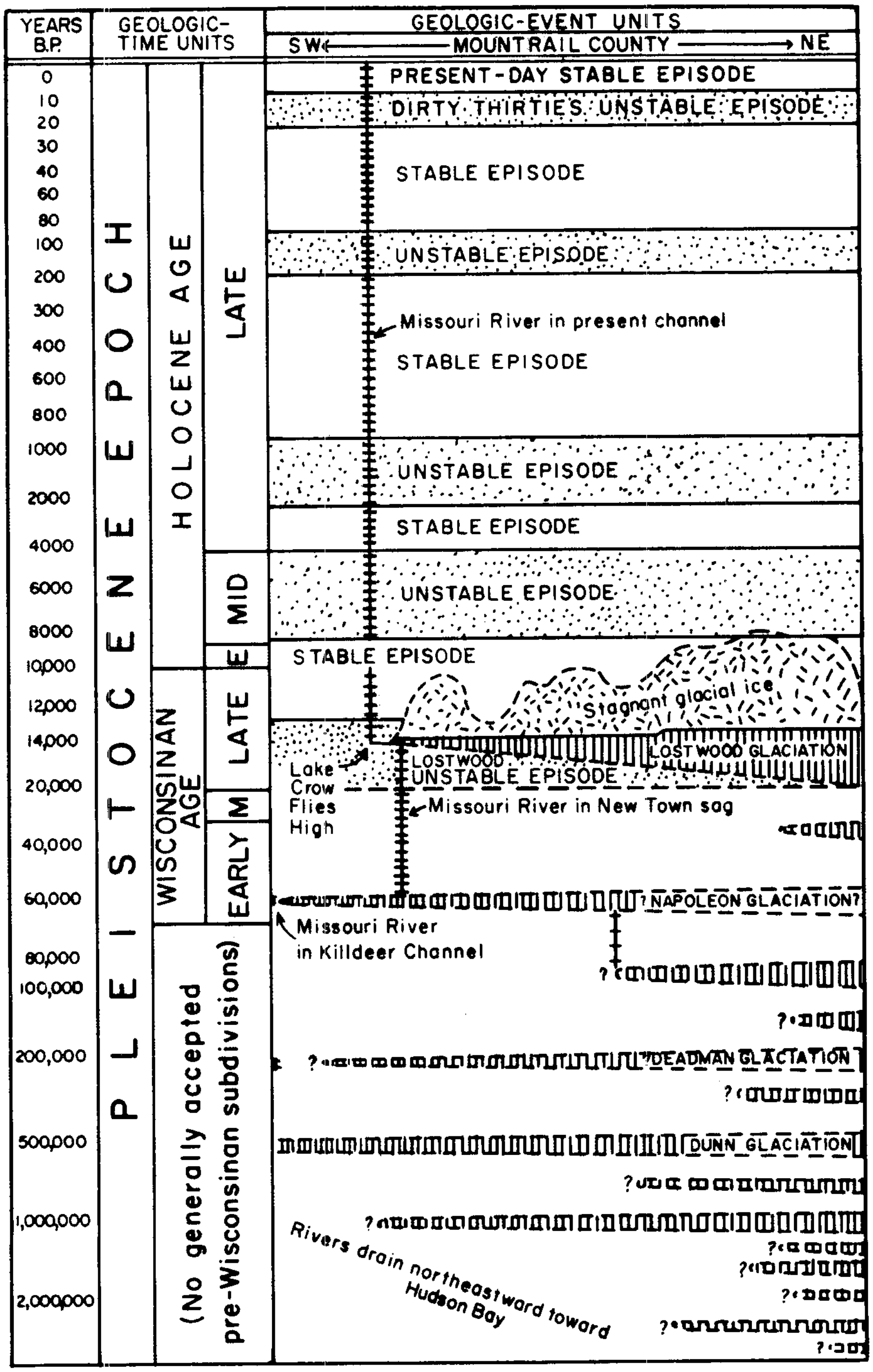

Figure 9.–Summary of the late Cenozoic history of northwestern North Dakota, along a southwest-northeast line through Mountrail County. Dashed lines indicate that the age of the bounded events is unknown.

In streams with upward seepage, there should be a positive (deviation-amplifying) feedback reaction between the seepage and erosion or deposition. That is, once some trigger causes a gaining stream to start degrading, the following reactions should result. (1) The water-table next to the stream steepens because of the degradation. (2) This causes the head that is driving the groundwater to increase. (3) This causes an increase in bank slumping (Terzaghi, 1950, p. 99). (4) This increase in bank erosion allows the stream to degrade more, causing a continuation of the feedback reaction. If, however, some trigger causes a stream to start to aggrade, (1) the water-table flattens, (2) the head decreases, (3) causing a decrease in bank erosion, (4) promoting further aggradation. This simplified relationship is complicated by many other variables. For instance, the degradation reaction would finally be stopped by factors such as the increased sediment supply from the oversteepened valley sides.

In streams with downward seepage, there should be a negative (deviation-damping) feedback reaction between the seepage and erosion or deposition. That is, if some disturbance causes degradation and a break in the mud seal in part of the bed of a losing stream, the following reactions should result. (1) Water rushes into the stream bed through the break in the seal, dragging mud into the pore space, causing the break to be re-sealed. (2) This hinders continued degradation at this spot because the new seal is stronger than the previous one if the water depth is greater. If, however, there is a mound on the stream bed or some disturbance causes aggradation in one part of the stream bed, (1) the stream depth is less, resulting in a smaller effective grain density (Harrison and Clayton, 1970, figure 6), (2) causing the competence to be greater there, (3) which hinders continued aggradation. Thus, in losing streams with a mud seal (such as those on alluvial fans) there is a tendency to resist either aggradation or degradation and a tendency to flatten the transverse profile of the stream.

Fluvial erosion cycles may be in part the result of the positive-feedback amplification of any small initial tendency to degrade or aggrade in gaining streams. Climatic changes, which influence erosion cycles by altering stream discharge, hillslope plant cover, hillslope runoff, and the sediment supplied to the stream (Schumm, 1965), may also influence the erosion cycles by altering the water-table position. Moister climates raise the water-table, causing an increase in seepage gradients and an increase in bank slumping, which promotes stream degradation. Conversely, dryer climates lower the water-table, causing a decrease in seepage gradients and a decrease in bank slumping, which promotes stream aggradation. As Schumm (1965) showed, however, this tendency is counteracted in arid areas by changing sediment supply.

## POSTGLACIAL STRATIGRAPHY

*Slough deposits.*–A rough calculation of the volume of postglacial slough-fills (mostly formation A on map 1) indicates that an average of roughly 1 foot of sediment has been washed from hillslopes in the rolling and hilly moraine areas during postglacial time. Dark clayey beds alternating with light-colored, more silty beds a few feet thick are probably the result of the same climatic changes interpreted from a study of slough stratigraphy on late Wisconsinan glacial deposits in Iowa by Walker (1966). The study of Hamilton (1967) indicates that hillslopes were unstable during dryer periods, resulting in the deposition of light-colored more silty sediment at the base of hillslopes (fig. 9). Spruce is commonly found in the lower dark clayey bed, representing a period of higher rainfall and hillslope stability about 13,000 to 10,000 years ago (Bickley, 1970).

*Stream deposits.*–Stream deposits (mostly formation B, map 1) commonly contain buried soils; the stratigraphic units exposed in the walls of arroyos in southern Mountrail County have been tentatively correlated by Hamilton with those observed along the Little Missouri River (Hamilton, 1967). The upper two alluvial units correlated with dry periods in the 1930's and the early 1800's (fig. 9).

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# CONTENTS OF POCKET

## Map 1: Descriptive Geologic Map of Mountrail County, North Dakota.
## Map 2: Interpretive Geologic Map of Mountrail County, North Dakota.

**Please note the following cartographic errors.**

Map 1.

Formation B, flat, is generally in the middle of the valley bottoms, and Formation B, apron, is generally along the sides of the valley bottoms.

Formation E occurs in sec. 2, T. 151 N., R. 93 W.; sec. 28, 31, and 32, T. 151 N., R. 92 W.; and sec. 5, T. 150 N., R. 92 W.

Formation F occurs in sec. 5, T. 152 N., R. 92 W.; the north edge of T. 153 N., R. 92 W.; the south half of T. 154 N., R. 92 W.; sec. 9, 23, and 25, T. 154 N., R. 93 W.; sec. 29, 30, 31, T. 158 N., R. 93 W.; sec. 36, T. 158 N., R. 94 W.; and adjacent areas.

Formation H occurs along the White Earth Valley (T. 157 N., R. 93 W.; and T. 154, 155, 156, and 157 N., R. 94 W.) and next to Lake Sakakawea (T. 151, 152, 153, and 154 N., R. 93 W.; T. 153 N., R. 92 W.; and T. 154 N., R. 94 W.).

The solid, dashed, and dotted geologic contacts have the significance indicated in the section on map reliability in the beginning of chapter 2 of section A.

The pebbly, sandy, silty clay of the Coleharbor Formation in NE¼ sec. 5, T. 155 N., R. 89 W. is nonintegrated hilly rather than flat.

The pebbly, sandy, silty clay of the Coleharbor Formation in SE¼ of sec. 30, T. 151 N., R. 90 W. is integrated hilly rather than nonintegrated undulating.

Map 2.

Post-Lostwood shoreline sediment should be shown brown rather than red in the explanation (examples on the map are around Cottonwood Lake and White Lake).

Post-Lostwood wind-blown sediment should be shown orange rather than red in the explanation (shown on the map near the northeast corner of T. 152 N., R. 90 W.).

Lostwood collapsed glacial sediment should be shown light green with red circles rather than yellow with red circles in the explanation.

Ice-walled rather than proglacial lake sediment in SE¼ sec. 17, T. 155 N., R. 90 W.; S½ sec. 34, T. 155 N., R. 90 W.; and SE corner sec. 1, T. 154 N., R. 94 W.

Napoleon rather than Lostwood glacial sediment in sec. 7 and 8, T. 152 N., R. 92 W.

Collapsed stream sediment rather than stream sediment deposited on solid ground in SE¼ sec. 14, T. 151 N., R. 91 W.

Erosional topography rather than collapsed glacial sediment in SE¼ sec. 30, T. 151 N., R. 90 W.