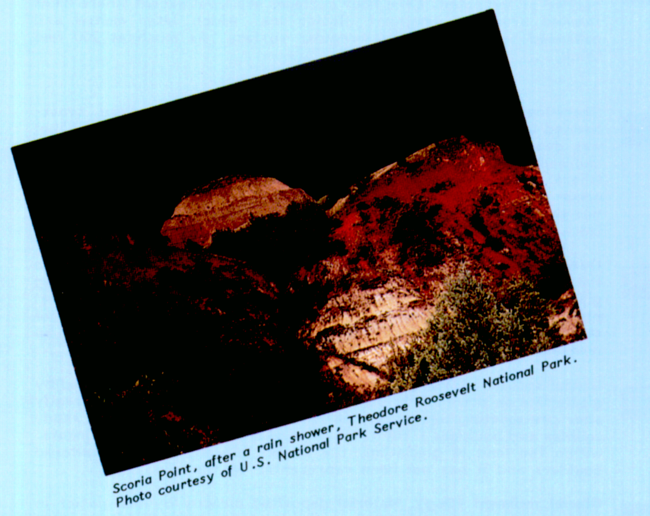
NORTH DAKOTA

Dahlen Esker, Grand Forks County.

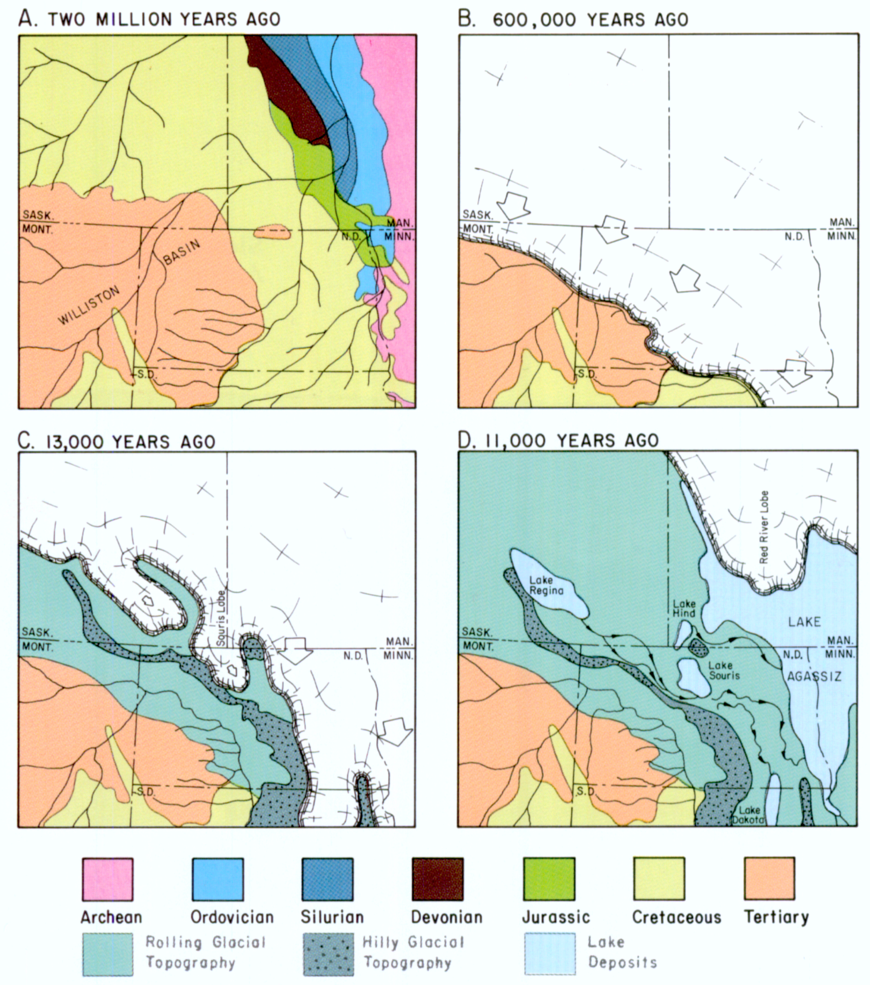


Scoria Point, after a rain shower; Theodore Roosevelt National Park. Photo courtesy of U.S. National Park Service.

Oil pumper in the Little Missouri River Badlands near Fryburg, Billings County.

GEOLOGICAL HIGHWAY MAP

North Dakota Geological Survey
Grand Forks, North Dakota 1988



REGIONAL HISTORICAL GEOLOGY

The four diagrams above show how the glaciers affected North Dakota and nearby areas during the Pleistocene Epoch, or "Ice Age." The first map shows conditions at the end of Tertiary time, just prior to the advance of the earliest glaciers. The oldest rocks, which were found at the edge of the Canadian Shield on the North Dakota-Minnesota border and to the north in Manitoba, consisted of igneous and metamorphic rocks of Archean age, some of which may have been as much as 2.5 billion years old. To the west, carbonates of Ordovician, Silurian, and Devonian age lapped onto the Canadian Shield. These were overlain in northeastern North Dakota and southern Manitoba by rocks of Jurassic age. Over much of the central and western part of the area, the land was covered by Cretaceous shales. Lignite-bearing sandstones, shales, and siltstones of Tertiary age were found in the Williston Basin, in western North Dakota and eastern Montana.

Before the Ice Age began, the area was a gently rolling plain that sloped to the north, toward Hudson Bay. Western North Dakota and eastern Montana were drained by northeast-flowing rivers that included the Yellowstone, Little Missouri, and, in Montana, the Missouri. Most of central North Dakota was drained by an extensive north-flowing river system that entered Manitoba east of the Turtle Mountains. This river drained areas that are today drained by the Knife, Cannonball, Heart and other rivers. Much of eastern North Dakota, parts of northwestern Minnesota, and northern South Dakota, were drained northward by an early Red River of the North. It's likely that all of these rivers joined somewhere to the north of North Dakota and that all of the runoff made its way to Hudson Bay.

The area was glaciated several times during the two-million-year duration of the Pleistocene Epoch, but our knowledge of early glaciations is extremely limited. Diagram B shows the hypothetical extent of one of the early glaciers, one that advanced perhaps 600,000 years ago. This early glacier blocked the northerly route of the Little Missouri River, forcing it to flow to the east and south, along the margin of the ice sheet. As a result of its new, steeper route, the Little Missouri River began eroding the badlands, a process that continues today. Each time glaciers advanced, probably a dozen times or more, they altered much of North Dakota's drainage, burying the then-existing drainage, and rearranging the drainage, so that new drainage patterns became established. After each glaciation, part of each new state-wide drainage pattern included a river that flowed south, toward the Gulf of Mexico. Whatever route this river took, it was considered to be an early version of the Missouri River, even though the exact routes of any of these early "Missouri Rivers" is not well known. The modern drainage in North Dakota is about 10,000 years old; some of the early routes of the "Missouri River" may have lasted much longer than that.

Even though the glaciers that covered North Dakota at various times during the Pleistocene Epoch flowed in various directions, evidence to document them is scarce. In parts of southwestern North Dakota, which were not reached by the most recent glaciers, the only evidence of the early glaciations is an occasional erratic, the remaining glacial sediment having been removed by erosion long ago. Only the most recent glaciation, the Wisconsinan glaciation, is well documented; all of the landforms and near-surface sediment in the northern and eastern part of the state were deposited by Wisconsinan glaciers.

Diagram C shows conditions when the ice was melting from North Dakota for the last time, at the end of the Wisconsinan glaciation. By 13,000 years ago, active glacial ice had melted from the central and northwestern parts of the state. Because the melting glacier by this time was much thinner than it had been several thousand years earlier, it could no longer flow over high areas such as the Turtle Mountains, Prairie Coteau, and Missouri Coteau (stippled areas on the diagram). Consequently, the glacier became more lobate and flowed around or along side these higher areas. Large portions of the glacier that had been flowing over the high areas became covered with debris, stagnated, and took much longer to melt than did the cleaner ice on the nearby lowlands. Areas where the ice stagnated remain today as rugged, hummocky moraine.

As the glacier continued to melt, large meltwater lakes became dammed along its southern edge (Diagram D). The largest of these was Lake Agassiz, but other meltwater lakes, such as Lakes Souris, Regina, Minnewaukan, and Dakota also formed in areas south of the receding glacier. When these lakes drained, broad, flat areas of silt and clay were left on the former lake bottoms.

SURFACE GEOLOGY OF NORTH DAKOTA

Western North Dakota's pre-Ice Age rock formations consist mainly of layers of siltstone and sandstone interbedded with layers of lignite coal and reddish "scoria," these beds form a unit geologists call the "Fort Union Group." Where Fort Union Group sediments are well exposed, as in the badlands near Medora, the layering is apparent. The Fort Union sediments were deposited by ancient rivers and streams flowing away from the rising Rocky Mountains at the time they were forming during the Paleocene Epoch, between 55 and 65 million years ago. Weathering and erosion of the rocks in the then newly-uplifted Rocky Mountains provided large amounts of sand and clay, which were washed eastward and deposited as beds of sediment on river floodplains and on deltas in shallow seas in western North Dakota where they are seen today as layered beds of sand and clay of the Fort Union Group. While the Fort Union sediments were accumulating, plants growing in swamps were converted to lignite coal or, in some places, they were transformed to petrified wood. The sedimentary layers contain fossil snail and clam shells, reptile and mammal skeletons, and a variety of plant fossils.

Southwestern North Dakota is part of the Great Plains, a broad, flat area that slopes eastward away from the Rocky Mountains in Montana and Wyoming. The landscape throughout this vast region is almost entirely a result of erosion, during the Pliocene and early part of the Pleistocene Epochs (since about 5 million years ago), of the Fort Union deposits. The beds of sand and clay have, in places, been transformed to natural brick ("scoria"), red layers that were baked by burning underground coal seams. In other places, mineral-rich groundwater circulated through the sediments, altering them to layers of silcrete, petrified wood, nodules, and concretions of all sizes and shapes. Such "secondary" processes (changes that took place in the sediments after they were deposited) account for the great differences in lithification and durability of the Fort Union sediments to modern erosion and weathering.

Little Badlands, Stark County. Photo by Bonnie L. Heidel.

The shapes of individual landforms throughout much of the unglaciated part of North Dakota are most notably the result of the differences in resistance of the near-surface materials to erosion by wind and running water. Buttes, for example, form when the harder, more resistant sandstone beds remain locally as protective caps on buttes when the softer surrounding silt and clay layers are eroded away. Although some parts of North Dakota southwest of the Missouri River were glaciated, the only evidence of the glaciation is an occasional boulder brought there by the glacier or an occasional patch of glacial sediment.

Petrified stump near Jones Creek, Theodore Roosevelt National Park.

The main reason the landscapes of western and eastern North Dakota differ markedly is because erosion has been going on much longer in the unglaciated parts of western North Dakota than in glaciated areas in the of east--several hundred thousand years in the west as opposed to about ten thousand years in the east. The composition and quality of the nonglacial sediments in the west are quite different from the composition and quality of glacial sediments in the east, and this also contributes to the different styles of erosion in the two areas. Landforms in the unglaciated areas southwest of the Missouri River owe their origin to removal by erosion of large amounts of sediment. The landforms in glaciated areas formed when sediments were dumped by the glaciers. Generally, hills and valleys are larger and farther apart in North Dakota's non-glaciated areas than in the glaciated areas. Nonglacial valleys are intricately carved, a product of small amounts of water eroding for many millions of years. In contrast, valleys of the glaciated areas were cut by large amounts of water--in some cases large floods--doing its work during and since the Ice Age, a much shorter span of time.

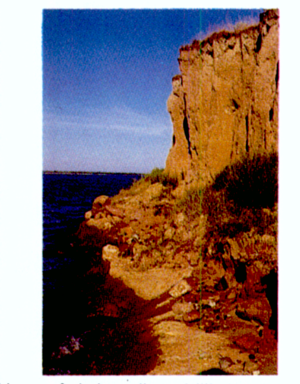
Sandstone cap on southwest face of Bullion Butte, Billings County. Photo by Ed Murphy.

The Little Missouri River began to carve the badlands sometime during the Pleistocene Epoch, perhaps 600,000 years ago, perhaps even earlier, when glaciers diverted the river from the route it then followed, into Saskatchewan. Following its diversion, the Little Missouri River flowed eastward over a shorter, steeper route, initiating a cycle of vigorous erosion that continues today.

Most of North Dakota north and east of the Missouri River was covered by glaciers several times during the Pleistocene Epoch (Ice Age) that ended about 10,000 years ago. When glaciers flowed over the preglacial surface, they picked up and transported great quantities of rock and soil, some of it great distances. When the glaciers melted, the materials contained in the ice were dropped on the ground, completely changing the shape of the North Dakota landscape. Sediments deposited by the glacier reach a total thickness as great as 750 feet in central North Dakota. The glacier sediment contains a diverse mix of rocks and minerals, making possible extremely rich soils, in contrast to the poorer soils developed on most of the Cretaceous and Tertiary formations found farther west in unglaciated areas.

Large meltwater trench west of Garrison, McLean County.

Water flowing from the melting glaciers deposited sand and gravel and eroded large valleys that are known as meltwater trenches; examples are the James, Souris, and Sheyenne River valleys. When the ice finally began to melt about 15,000 years ago, it generally dropped its load of sediment, but in some places, large amounts of debris remained in and on top of the glacier, so that, as the ice melted, thick layers of that debris became concentrated at the surface of the glacier. The mantle of rock and sediment on top of the glacier was so thick that it insulated the ice and retarded its melting for several thousand years. When the last of the ice finally did melt, these overlying materials slumped and slid, forming deep potholes and an irregular surface that has not changed much to the present day. The areas of "hummocky moraine" that resulted are found today in the Turtle Mountains and on the Missouri Coteau.



Exposure of layers of glacier sediment (till) along Lake Sakakawea, McLean County.

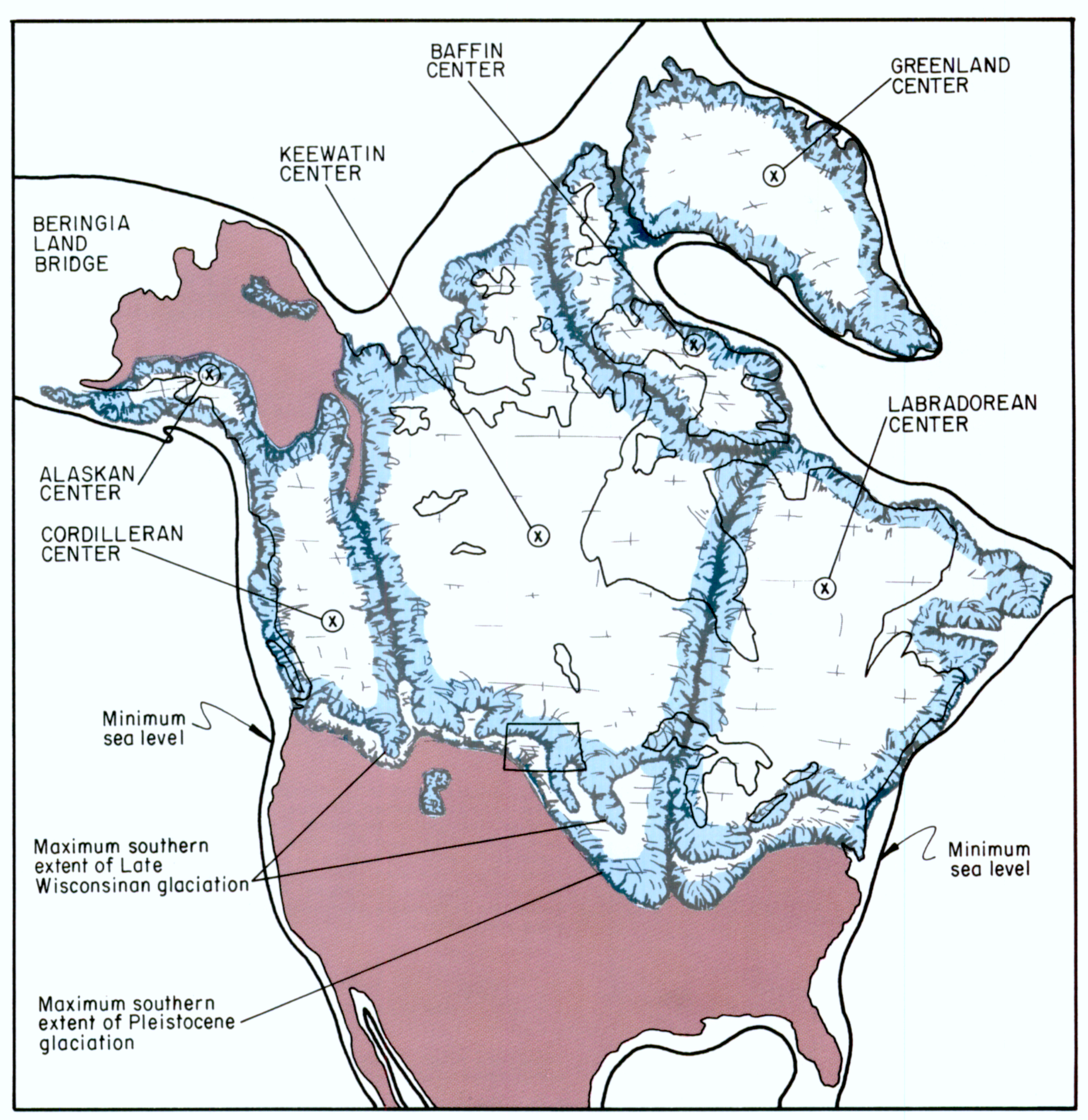
Less debris accumulated on the surface of the glacier over most of the lowland areas and, when this relatively clean ice melted, a gently rolling surface (the "Glaciated Plains") resulted. In other places, the ice shoved large masses of material, forming hills ("thrust blocks") near the glacier margin. In still other places, loose accumulations of rock debris piled up at the edge of the glacier, resulting in areas of especially hilly land ("end moraines"). Rivers of water from the melting ice flowed through cracks and tunnels in the glacier, depositing thick beds of gravel. When the walls of ice eventually melted away, the gravel beds slumped down and were left as esker ridges. In places where rivers of sediment-laden water flowed away from the melting ice, broad outwash plains underlain by thick deposits of gravel formed.

McHenry moraine, ice-marginal glacier deposits, Eddy County.

As the end of the Ice Age neared, and the glaciers receded northward, large lakes were dammed at the margin of the melting ice because the rivers and streams, which before the Ice Age had flowed down the regional northerly slope to Hudson Bay, were still blocked by the vast glacier to the north. Great quantities of sand, silt, and clay were carried to these lakes by the rivers flowing into them. The lakes eventually drained away when the ice melted farther back, and broad, flat expanses--the former lake floors--remained. The largest of the glacial lakes was Lake Agassiz, which flooded part of eastern North Dakota (the Red River Valley) along with vast areas of Manitoba, Ontario, and Minnesota. Ancient beaches, built along the shore of Lake Agassiz, can still be seen today. Other lakes of glacial meltwater that were dammed south of the receding glacier were Lake Souris in north-central North Dakota, Lake Dakota in the southeast, and Lakes Cando and Minnewaukan (glacial Devils Lake) in the northeast.

In most parts of North Dakota, the modern landscape is little changed from the way it was at the end of the Ice Age, about 10,000 years ago. Rapid erosion has continued in the badlands areas and, in some places, broad expanses of sand that were deposited by rivers flowing in the glacial lakes have, during the past ten millennia, been blown into dunes by the wind. Spectacular dune fields can be seen in the Denbigh, Walhalla, and Towner areas. The dunes are mostly stable now and covered by vegetation.

Ice-thrust hills, Eddy County.



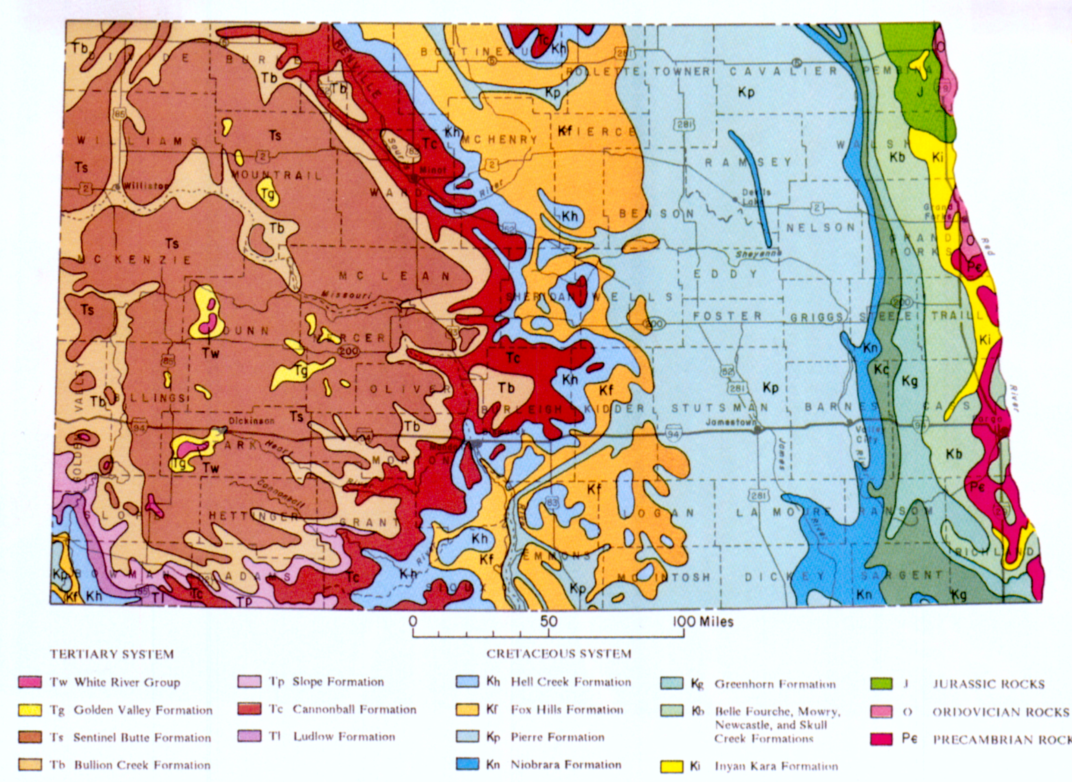
LATE PLEISTOCENE GLACIATION

The Pleistocene Epoch is often referred to as the Ice Age since continental ice sheets spread across Canada and the northern United States during this time. Evidence from North Dakota and elsewhere suggests several major periods of glaciation during the two million years of the Pleistocene Epoch, each lasting for thousands of years. The maximum extent of the glaciers that covered North America during the Pleistocene is shown on the figure above (the lighter blue, southernmost ice border). The glaciers that advanced into North Dakota profoundly influenced the topography we see here today.

During the most recent glaciation, called the Wisconsinan, which started approximately 75,000 years ago, the glaciers didn't advance quite so far as had some of the earlier ones (the Wisconsinan ice margin is shown by the inner blue boundary on the map). The glaciers fluctuated back and forth between northerly and southerly regions before they finally retreated from North Dakota about 9,000 years ago. Though the climate began to warm about 16,000 years ago, it was nearly 4,000 years before the ice melted from most of eastern North Dakota; the ice on the Missouri Coteau and Turtle Mountains took another 3,000 years to melt away completely.

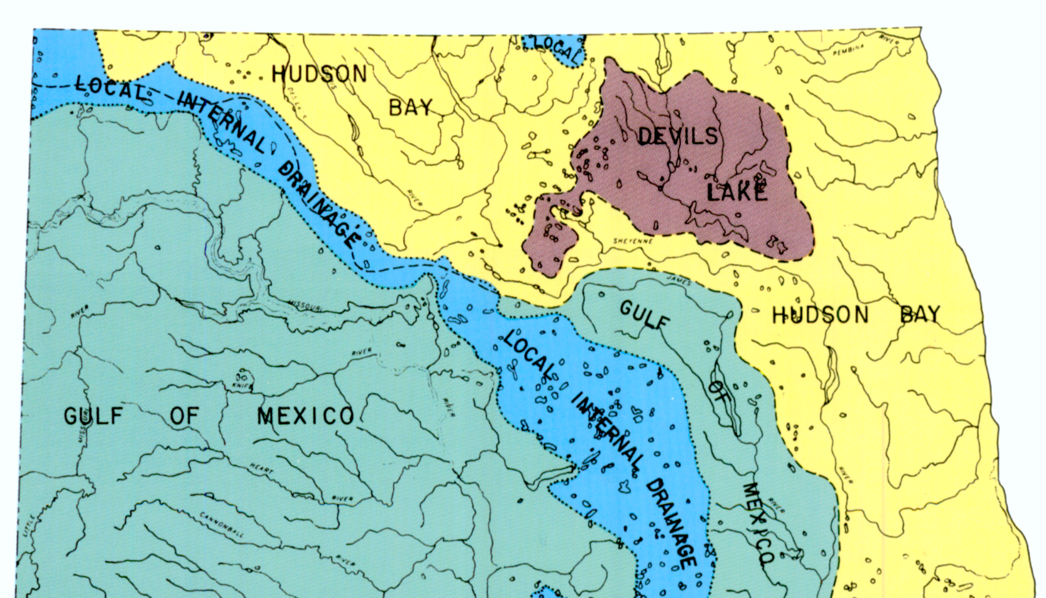
The load of the ice resulted in crustal depression. Slow rebound of the earth's crust followed the retreat of the glaciers; since the ice was thicker and heavier in the north than in the south, the amount of crustal depression (and subsequent rebound) was more in the north. It is theorized that the earth's crust was depressed about one foot for every three feet of ice and the ice was several thousand feet thick in northeastern North Dakota. Crustal rebound is still taking place to the north of North Dakota; in the Hudson Bay area, near Churchill, where the ice was much thicker and melted more recently, the land is still rising at the rate of 4 feet per century.

North Dakota's modern landscape bears the legacy of these late Pleistocene glaciations which eroded and reshaped the land surface. Broad areas of hummocky moraine formed when thick layers of stagnant glacial ice melted over the Turtle Mountains and the Missouri Coteau. Hilly areas of intensely thrust topography such as Sully's Hill are found in parts of eastern North Dakota along with ranges of rugged hills like the Martin and Burnstad moraines. Eskers like those at Dahlen and Benedict occur where rivers once flowed in tunnels and cracks in the glacier. The Missouri and Sheyenne valleys are just a few of the routes used by water flowing from the melting water from the melting ice. Meltwater lakes like Lake Souris and Lake Agassiz are also the result of glaciation. Broad areas of sand dunes found on old river deltas in the lake plains were shaped by the wind in the time since the end of the glacial epoch. Even in southwestern North Dakota, which was never reached by the glaciers, a tundra climate during the Pleistocene resulted in frost polygons and other frozen-ground features, many of which persist today. The badlands of the Little Missouri River resulted when a north-flowing river was blocked; after the Little Missouri River was diverted, it began to carve the badlands topography we see today.

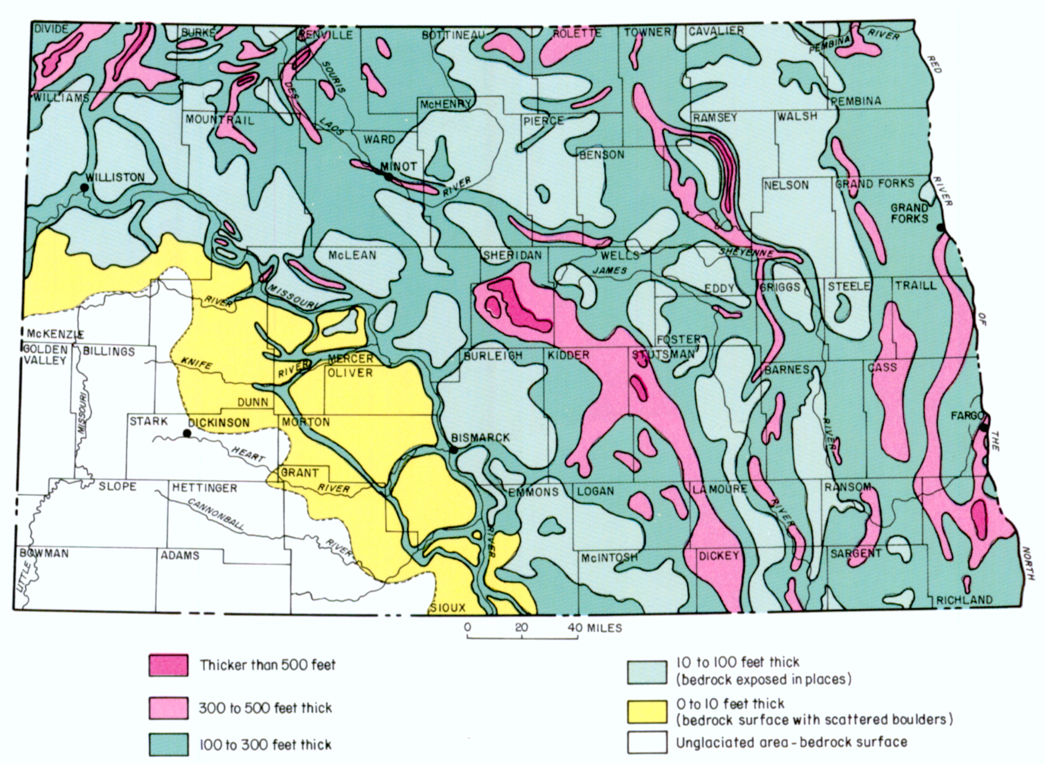


BEDROCK GEOLOGY OF NORTH DAKOTA. The above map shows the geology of North Dakota beneath the covering of glacial deposits. The oldest rocks in the state are Archean (Precambrian) metamorphic rocks found along the Minnesota border. Ordovician and Jurassic carbonate and sandstone formations are found beneath the glacial sediments in the northeastern corner of the state and progressively younger formations occur to the west, toward the center of the Williston Basin (see the cross section beneath the map on the other side of this sheet). The circular shape of the Williston Basin is apparent from the map; the Tertiary Cannonball Formation forms part of semi-circle around the edge of the basin, for example.

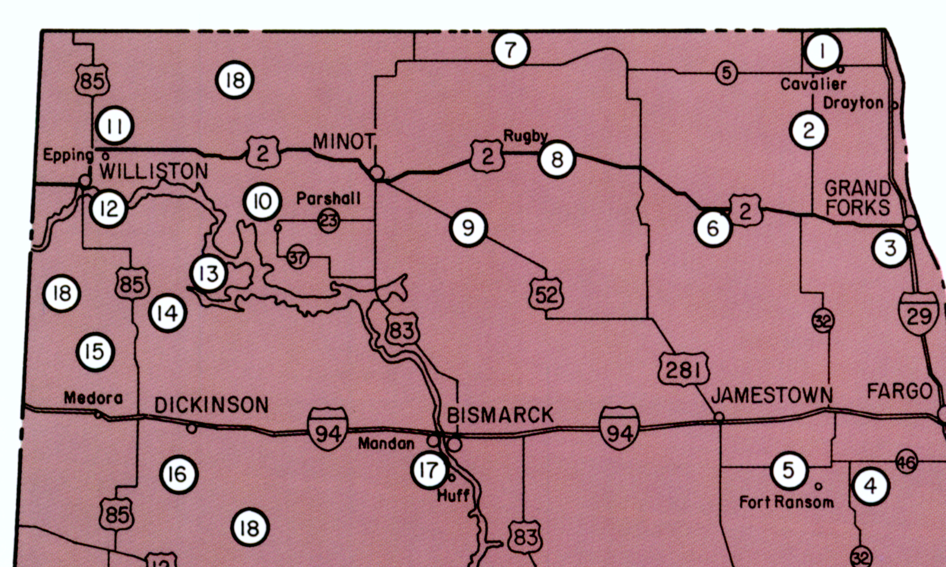
Most of eastern North Dakota has a covering of Cretaceous shale formations. In the central and western areas, Cretaceous and Tertiary sandstones predominate. The youngest bedrock formations are the Tertiary units of Oligocene and Miocene age found on the tops of some of the higher buttes, such as the Killdeer Mountains.



MODERN DRAINAGE. North Dakota has a total area of 69,300 square miles. Of this, approximately 30,000 square miles (43% of the total land area) drains to Hudson Bay by way of the Red River and 27,000 square miles (39%) drains to the Gulf of Mexico by way of the Missouri River. In addition, approximately 3,800 square miles (6%) drains to Devils Lake and another 8,500 square miles (12%) is essentially undrained; this includes the Turtle Mountains, Missouri Coteau, and Prairie Coteau.



THICKNESS OF GLACIAL SEDIMENTS IN NORTH DAKOTA. This map shows the thickness of glacial sediments overlying the preglacial (bedrock) surface. Areas of thickest sediments are found in buried preglacial and interglacial river valleys and on the Missouri Coteau. Southwestern North Dakota (the uncolored area) was not glaciated.



POINTS OF GEOLOGIC INTEREST

1. Pembina Hills area. The Pembina River has carved a scenic trench through the Cretaceous Pierre, Niobrara, and Carlile Formations and into the Greenhorn Formation. The Greenhorn Formation shale, the oldest exposed bedrock formation in North Dakota, is found only in the Pembina Hills.
2. Dahlen Esker. Crossed by State Highway 32 at the Grand Forks-Walsh County line: one of the most spectacular eskers in North America.
3. Grand Forks Geology Department Museum, University of North Dakota campus. Numerous geologic displays featuring an excellent triceratops skull.
4. Sheyenne Dunes. Scenic dune field on sandy delta in the McLeod area. The sand was deposited at the mouth of the Sheyenne River where it flowed into glacial Lake Agassiz; wind erosion of the sand during the past 10,000 years blew the sand into dunes.
5. Sheyenne River valley near Fort Ransom. Scenic glacial meltwater trench.
6. Devils Lake and Sully's Hill. When the prominent hills south of Devils Lake were emplaced by glacial thrusting, a broad depression resulted. This depression is now flooded by Devils Lake.
7. International Peace Garden in the Turtle Mountains. Formal gardens and parks in a setting of wooded, hummocky moraine, the result of large-scale glacial stagnation.
8. Geographical Center of North America, Rugby.
9. Anamoose. The hill along U.S. Highway 52 just southeast of Anamoose is an ice-thrust mass that was transported by the glacier from the depression, now flooded by a lake.
10. Paul Broste Rock Museum, Parshall. Features a display of sapphires.
11. Buffalo Trails Museum, Epping.
12. Flying J Oil Refinery, east of Williston. Tours by appointment.
13. Little Missouri Bay State Park, near Mandaree off State highway 22. Scenic badlands, carved from beds of the Paleocene Sentinel Butte Formation.
14. Killdeer Mountains. Two large buttes with a caprock of Oligocene and Miocene limestone and sandstone.
15. Theodore Roosevelt National Park, north of Medora: north and south units of the park and the Elkhorn Ranch Site are located in the North Dakota badlands, carved out of beds of sand, clay, lignite, and scoria of the Sentinel Butte and Bullion Creek Formations.
16. South Heart badlands southwest of Dickinson. Oligocene White River Formation badlands topography; vertebrate fossil bones.
17. Amoco Oil Refinery. Tours by appointment.
18. Generalized area of North Dakota oil and gas fields.

PURPOSE OF THE MAP

The Geologic Highway Map of North Dakota is intended to be used as a general reference map to familiarize the reader with North Dakota's diverse and interesting geology. The extensive nature of the subject material makes it impossible to provide a detailed treatment of the geology. Rather, this map is intended simply as a source of general information and as a starting point to further research on North Dakota's geology. A selected listing of references with detailed and specific information has been provided for such research.

Compiled by:
John P. Bluemle
1988

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Cartography and drafting by Ken L. Dorsher

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North Dakota Geological Survey
Miscellaneous Map 29

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GEOLOGIC HIGHWAY MAP OF NORTH DAKOTA

North Dakota Geological Survey
Miscellaneous Map 29

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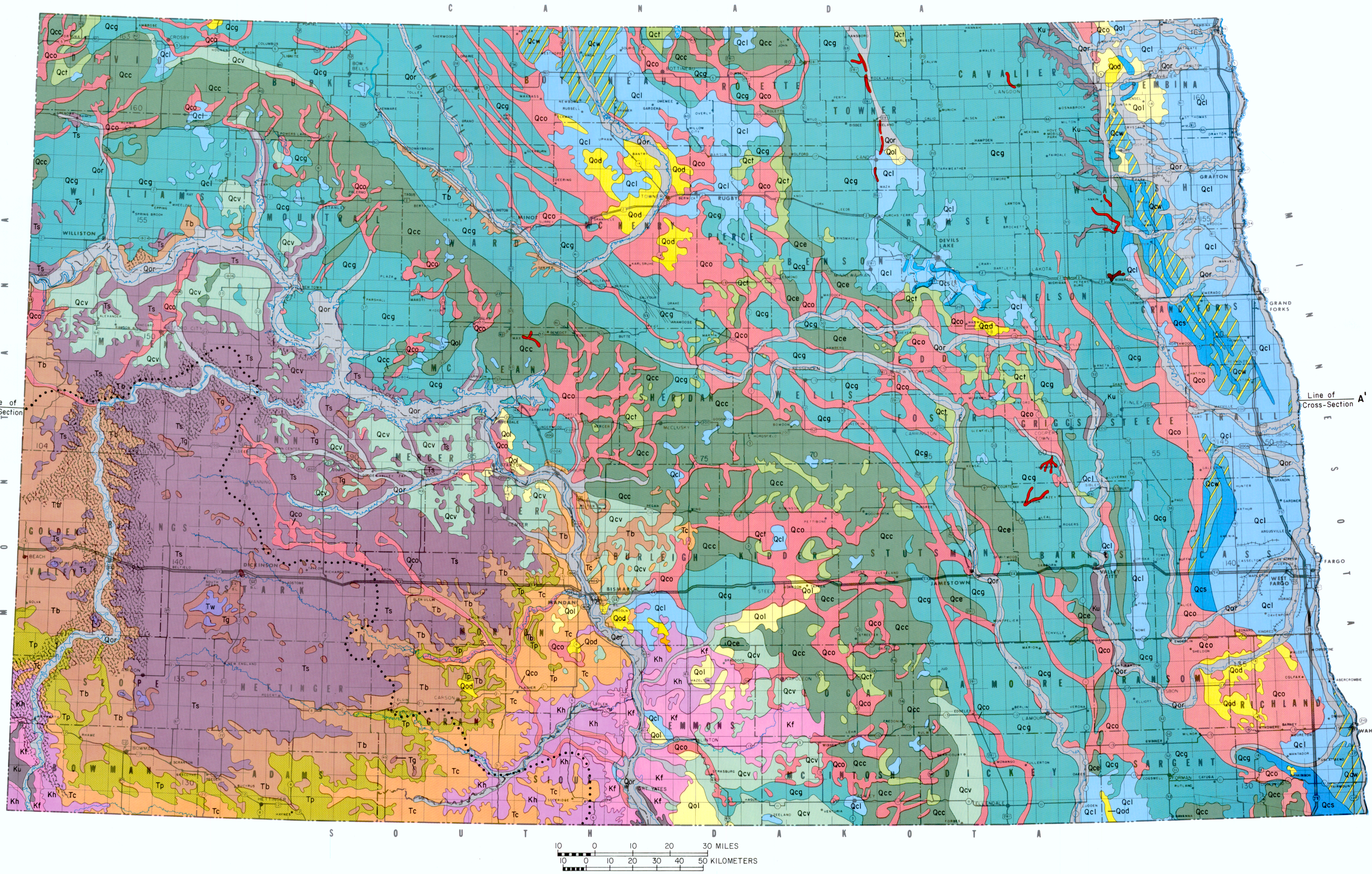

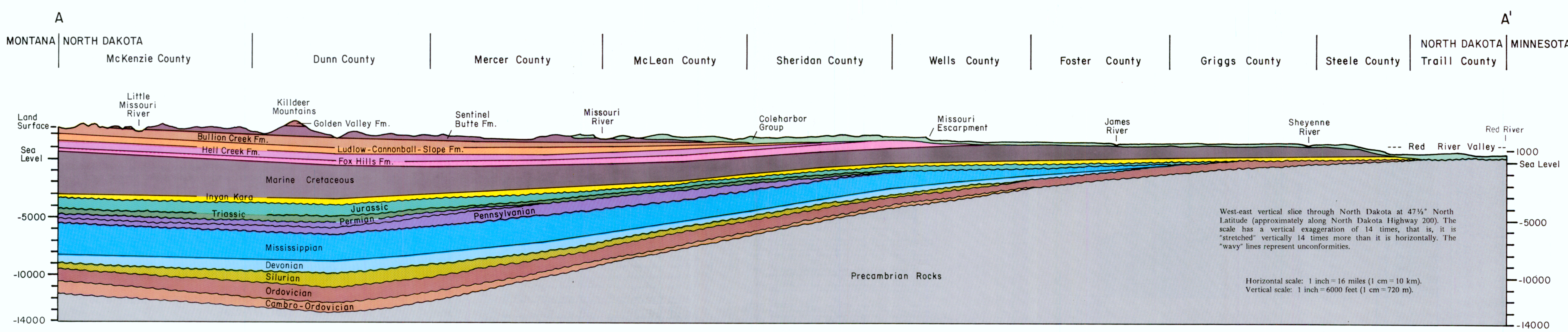

West-east vertical slice through North Dakota at 47½° North Latitude (approximately along North Dakota Highway 200). The scale has a vertical exaggeration of 14 times, that is, it is "stretched" vertically 14 times more than it is horizontally. The "wavy" lines represent unconformities.

Horizontal scale: 1 inch = 16 miles (1 cm = 10 km).
Vertical scale: 1 inch = 6000 feet (1 cm = 720 m).

EXPLANATION

In some places, such as in badlands and in hilly areas covered by glacial deposits, the geologic materials indicated on the map may be seen at the surface of the ground. In many level areas, however, soil completely covers the indicated geologic materials to a depth of several feet.

The composition, origin, and typical surface expression of each of the map units are included in the explanation. In all cases, the capital letter designation refers to the age of the unit. The first lower case letter identifies the formation or group and the second lower case letter (where applicable) identifies a particular type of lithology or topography that can be recognized within the formation or group.

Holocene

OAHE FORMATION

The Oahe Formation consists of river, wind, pond, and slough sediment that was deposited during the Holocene Epoch. Although tens of thousands of ponds and sloughs occur in North Dakota, most of them are too small to show at the scale of this map.

Qor — **River and stream overbank sediment (Qor).** Alluvium and slopewash deposited on level floodplains along the larger rivers and streams since the end of the Pleistocene Epoch. Dark, mainly obscurely bedded clay, silt, sand, and gravel with dispersed organic material. Usually less than 5 feet thick.

Qod / Qol — **Windblown sediment (Qol and Qod).** Well sorted, medium to fine grained sand and silt; includes both loess and dune sand. Dunes (Qod) are as much as 75 feet high, generally stabilized by vegetation; active blowouts are common. Loess deposits (Qol) consist of bedded silt that is as much as 10 feet thick on level uplands. Widespread thinner deposits are not shown on the map.

Pleistocene

COLEHARBOR GROUP

The Coleharbor Group consists of materials that were deposited by glaciers, rivers, and lakes during the Pleistocene Epoch. Thicknesses may exceed 800 feet in buried preglacial valleys and diversion trenches, but the average thickness is between 50 and 250 feet over most of eastern and northern North Dakota.

Qcl — **Lake sediment (Qcl).** Silt and clay deposited mainly offshore on the floors of proglacial lakes; moderately to well sorted, usually flat bedded or laminated. Lake floor surfaces are level except where lakes flooded areas of stagnant glacier ice, which later melted and collapsed, resulting in an irregular surface. As much as 200 feet thick.

Qcs — **Shoreline sediment (Qcs).** Moderately to well-sorted, clean, cross-bedded to flat-bedded gravel and sand. Beach and shore sediment that was deposited along the shores of proglacial lakes. The only beach sediments shown on this map are along the shore of Lake Agassiz where well-developed beach ridges occur. Similar shore sediments occur in places along other glacial meltwater lakes in North Dakota, but they are too limited in extent to show on a map of this scale; as much as 15 feet thick.

Qco — **Outwash sediment (Qco).** Moderately to poorly sorted, crossbedded to flat-bedded gravel and sand deposited by water flowing from melting glaciers as well as by runoff from precipitation. Commonly broad, flat plains except in places where materials were deposited on top of stagnant glacier ice, which later melted and collapsed, resulting in an irregular surface; as much as 100 feet thick.

Qcv — **Glacial sediment (Qcv).** Discontinuous veneer of material deposited by glacier ice on pre-Pleistocene formations; the veneer does not greatly alter pre-existing topography. Unsorted mixture of clay, silt, sand, cobbles and boulders ("till"). In parts of southwestern North Dakota, within the limit of glaciation, the veneer consists only of scattered boulders and it has not been represented on the map.

Qcg — **Glacial sediment (Qcg).** Material deposited directly by the glacier in sufficient amounts to cover and mask pre-existing topographic features. Unsorted mixture of clay, silt, sand, cobbles, and boulders ("till"). Undulating collapsed topography with gently rolling relief that has commonly been referred to as "ground moraine." As much as 100 feet thick, although multiple-event deposits may be much thicker.

Qce / Qcc — **Glacial sediment (Qce and Qcc).** Unsorted mixture of clay, silt, sand, cobbles, and boulders ("till"). Qcc: material deposited during large-scale glacial stagnation; hummocky collapsed topography ("dead-ice moraine") with hilly topography and abundant ice-disintegration features. Qce: material deposited at the margin of a melting glacier ("end moraine") with hilly topography and strong internal linearity. Both Qcc and Qce are present in thicknesses sufficient to mask pre-existing topography.

Qct — **Glacial sediment (Qct).** Unsorted mixture of clay, silt, sand, cobbles, and boulders ("till"), commonly with large inclusions of preglacial bedrock, outwash sediment, or lake sediment. Ice-thrust topography consisting of material that has been moved, in large slabs or blocks, by the thrusting action of glacial ice near the terminus of an active glacier. Moderate to high relief; may be several hundred feet thick.

Qcw — **Glacial sediment (Qcw).** Material deposited by the glacier (mainly till) and later washed by running water or by waves along the shores of lakes. Commonly with a lag of boulders or a discontinuous veneer of gravel and sand (shore or river sediment).

Oligocene

WHITE RIVER GROUP

Tw — Pinkish siltstone and dark clay with some sand and freshwater limestone; silty bentonitic claystone; pebbly in places. Lake and river sediment. Commonly found on hills and buttes; as thick as 250 feet.

Eocene

GOLDEN VALLEY FORMATION

Tg — Bright-colored, yellowish, clayey and sandy layers. Lake and river sediment. Commonly found on hills, along the sides of buttes, and over upland areas; as thick as 250 feet.

Paleocene

SENTINEL BUTTE FORMATION

Ts — Dull gray layers of silt, clay, and sand with interbedded sandstone, lignite, baked clay, and limestone. Delta, lake, and river sediment. Forms rolling topography over broad areas and has been eroded to badlands near rivers; as thick as 650 feet.

BULLION CREEK FORMATION

Tb — Yellowish layers of silt, clay, and sand with interbedded sandstone, lignite, baked clay, and limestone. Delta, lake, and river sediment. Forms rolling topography over broad areas and has been eroded to badlands near rivers; as thick as 650 feet.

SLOPE FORMATION

Tp — Gray-brown and yellow-brown silt, sand, clay, sandstone, and lignite; river, lake, and swamp sediment; as thick as 300 feet.

CANNONBALL AND LUDLOW FORMATIONS (undifferentiated)

Tc — Yellowish gray to brown (Ludlow) and yellowish sandstone and mudstone with some limestone (Cannonball). Ludlow: delta, lake, and river sediment; Cannonball: tidal flat, estuary, shore, and offshore marine sediment. Gently rolling topography; as thick as 600 feet.

Cretaceous

HELL CREEK FORMATION

kh — Dark gray to maroon, bentonitic clay, shale, and gray to light-colored sand and silt; concretions and fossil dinosaur bones in places. Delta, lake, and river sediment. Forms rolling topography in most places, but has been eroded to badlands near buttes and along rivers; as thick as 500 feet.

FOX HILLS FORMATION

kf — Brown to gray shale and sandstone with loose sand in places; fossil oysters and clams common. Mainly marine coastal sediment. Forms rolling topography with smooth slopes in most places; as thick as 400 feet.

GREENHORN, CARLILE, NIOBRARA, AND PIERRE FORMATIONS (undifferentiated)

ku — Greenhorn: white mottled, dark gray calcareous shale (exposed only in the Pembina River Valley in the northeastern corner of the state); Carlile: dark gray shale (exposed only in the Pembina River Valley in the northeastern corner of the state); Niobrara: calcareous, medium gray shale (exposed only in eastern North Dakota); Pierre: light gray to medium gray shale with ironstone concretions. All three formations are offshore marine sediments. Topographic expression is limited mainly to isolated exposures along river valleys.

MISCELLANEOUS SYMBOLS

Compaction ridge. Ridge on the Lake Agassiz plain that marks the former route of a river; usually gravel or sand.

Drumlin. Ridge that formed parallel to the glacier movement; usually till or sand.

Esker. Long, narrow, sinuous ridge of stratified glacial sediment, usually gravel, deposited by a stream that flowed on, within, or beneath the glacial ice.

Badlands. Areas dissected by stream erosion into an intricate system of closely spaced, narrow ridges.

Maximum extent of glaciation.

NORTH DAKOTA CENTENNIAL

NORTH DAKOTA GEOLOGICAL SURVEY 1895