GEOLOGY ALONG NORTH DAKOTA INTERSTATE HIGHWAY 94

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The modern, uncrowded highways of North Dakota carry you through a fertile, unspoiled land that lies beneath a broad, clear sky. We hope to deepen your perspective of our state by explaining how the landscape along Interstate Highway 94 formed. Perhaps we can add to the enjoyment of your trip by calling your attention to some of the geologic features along the highway.

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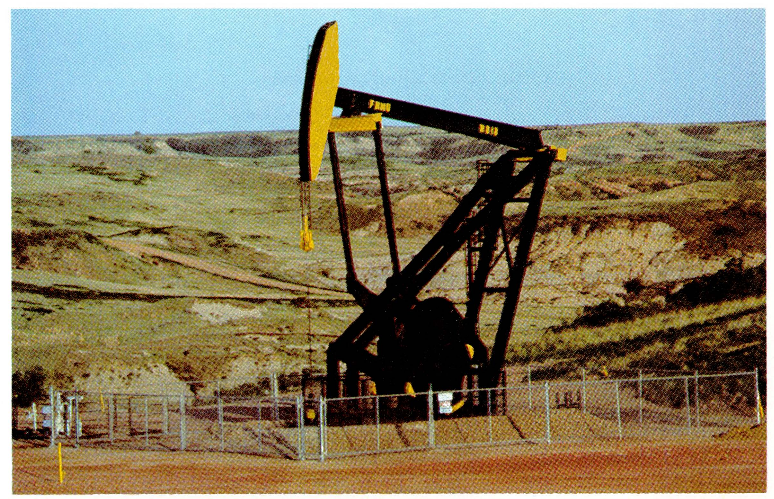
State Geologist

The broad, open spaces of western North Dakota are underlain by thick sequences of sediment that contain oil, gas, and lignite coal. The landscape is marked by numerous buttes capped by layers of erosion-resistant rock that keeps them from being eroded away.



This well is pumping oil from the Fryburg Oil Field, just south of Theodore Roosevelt National Park. Nearly 700 million barrels of oil have so far been produced in North Dakota.

Sentinel Butte, viewed over the village that bears the same name. The butte is said to have been named for two Arikara Indian sentinels, American Black Eagle and Standing Together, who were killed by a Sioux war party in this area. The butte is capped by a layer of resistant rock of Tertiary age.

GEOLOGY OF NORTH DAKOTA

The pre-ice age rock formations that can be seen in western North Dakota consist mainly of layers of siltstone and sandstone interbedded with layers of lignite coal and reddish "scoria." Where the sediments are well exposed, as in the badlands near Medora, the layering effect is readily apparent. The pre-ice age sediments were deposited by ancient rivers and streams flowing from the Rocky Mountains during the youthful stages of these mountains. Weathering of the newly uplifted Rocky Mountains produced sand and clay that was washed eastward onto the plains. It is these sand and clay beds that we see today in western North Dakota. At times, while this deposition was taking place, plants that grew in swamps were later converted to lignite or, in some places, petrified wood. Some of the clay layers contain fossil snail and clam shells, reptile and mammal skeletons, and various plant fossils. Most of the sand and clay beds exposed in western North Dakota were deposited more than 30 million years ago.

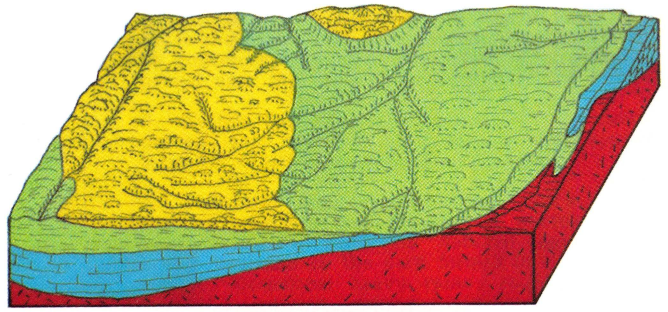
Much later, when the area drained and erosion began, the harder, more resistant sandstone beds remained locally as protective caps on buttes that formed as the softer silt and clay layers were eroded away. Partly because erosion has been going on much longer in the unglaciated areas of western North Dakota than in the glaciated areas of eastern North Dakota, and partly because the composition and quality of nonglacial sediments are different from the composition and quality of glacial sediments, the landscapes of western and eastern North Dakota differ markedly. The hills in the unglaciated areas are entirely the result of removal by erosion of the surrounding layers of sand and clay, whereas the hills in the glaciated areas are primarily the result of dumping of sediments by the glaciers. In general, non-glacial hills are larger and farther apart than are hills in glaciated areas. The valleys of the non-glacial areas are more intricately carved because they are the result of small amounts of water eroding the area for many millions of years. The valleys of the glaciated areas were cut by large amounts of water doing its work during and since the ice age, a much shorter time.

All of North Dakota, except for the southwest quarter, was covered by glaciers several times during the ice age that ended about 10,000 years ago. When the glaciers moved over the preglacial surface, they carried with them great quantities of rock and soil that they picked up and pulverized into a mixture known as till. Water flowing from the ice deposited sand and gravel and carved large valleys known as meltwater trenches. When the ice finally stopped moving, it melted and dropped its load of sediment. In areas of dead-ice moraine, so much sediment remained on top of the ice that it insulated and retarded the melting of the ice for several thousand years. When the ice finally did melt, the overlying materials slumped and slid, forming deep potholes and an irregular surface that has not changed much to the present day.

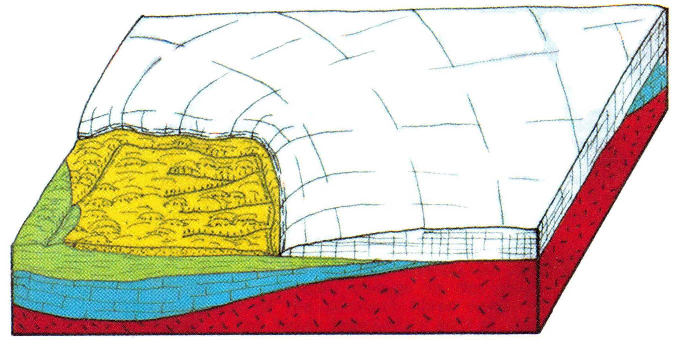
In some areas, less sediment accumulated on the surface of the glacier, whereas greater amounts of sediment accumulated near the edge of and beneath the glacier. In places, loose accumulations of rock debris piled up at the edge of the glacier, resulting in areas of especially hilly land. Areas where the ice deposited sediment at its base as it moved along are less hilly, but still rather rolling. The till in such areas is generally hard and compact because it was packed by the ice that overrode it.

Finally, as the ice age ended, large lakes were dammed ahead of the melting ice because the preglacial drainage routes, which had been northward, were still blocked by ice. Great quantities of sand, silt, and clay were deposited in these lakes by the many rivers that flowed into them. The water eventually drained out when the ice melted farther back, and broad, flat expanses of lake plain remained. The largest of these is the Agassiz lake plain in eastern North Dakota. Ancient beaches can be seen today along the former shorelines of Lake Agassiz.

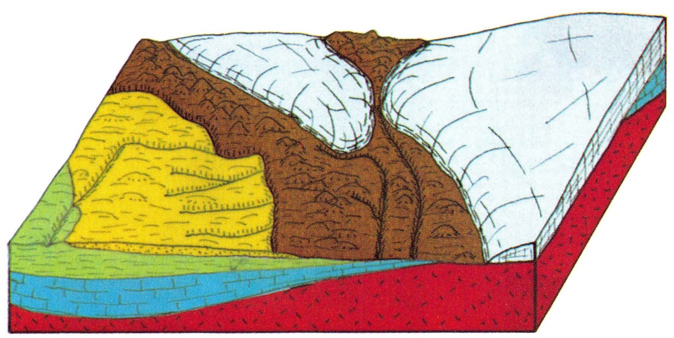
Groundwater is the most important mineral resource associated with the glacial sediments in North Dakota. Sand and gravel are also important and small amounts of ceramic quality clays, riprap boulders, and sodium sulphate are taken from the glacial sediments. Mineral resources found in the non-glacial sediments include oil and gas, lignite and associated uranium, high-grade clay, leonardite, volcanic ash, bentonite, potash, salt, and sulfur.



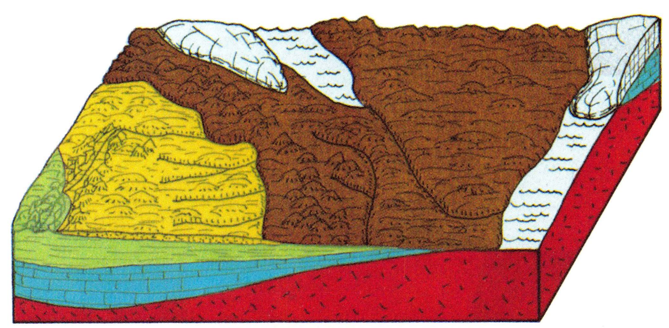
1. North Dakota just before the ice age. The main preglacial drainage routes are shown on this block diagram, which also depicts the subsurface geologic formations. The locations of the streams shown here reflect our knowledge that preglacial drainage was generally northeastward. Most of the land surface was probably relatively smooth, particularly in the eastern half of North Dakota where shale of Cretaceous age was exposed (green areas). In the easternmost part of the state, limestone of Paleozoic age (blue areas) and some Precambrian granite (red areas) were exposed. Tertiary age sandstone, shale, and lignite beds (yellow areas) covered much of the western part of the state.



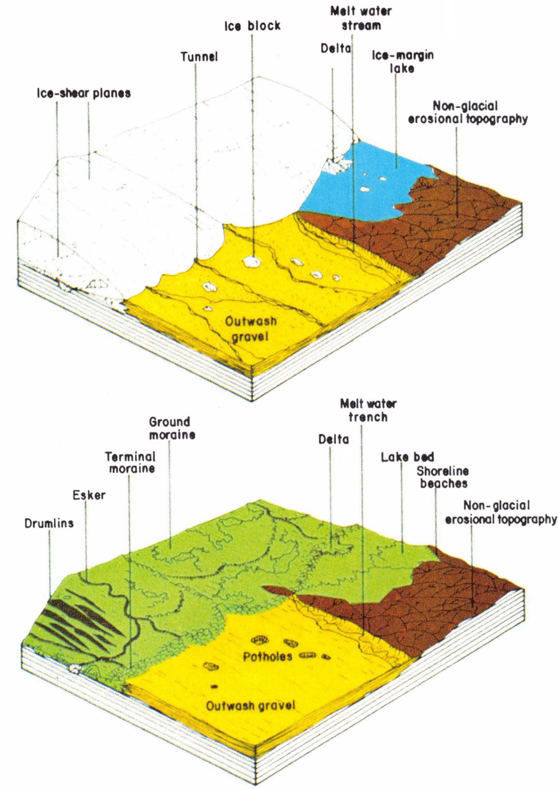
2. North Dakota during the ice age at a time after the glaciers had already reached their maximum extent and had begun to melt back into Canada. The glacial ice acted as a barrier to the northeast-flowing streams, diverting them southeastward so that they combined to form the Missouri River. Water from the melting ice also contributed to the river. Erosion had by this time begun its work of carving the rugged badlands along the Little Missouri River in southwestern North Dakota.



3. The glacier had melted back to the position shown on the above block diagram by about 12,000 years ago. The brown on this and the following diagram represents land that was covered by glacial deposits. As the glaciers melted back, they left several tens to several hundreds of feet of gravel, silt, and till lying on the older, nonglacial rock formations. Water from the melting ice continued to erode valleys such as the James and Sheyenne River Valleys in the eastern part of the state.



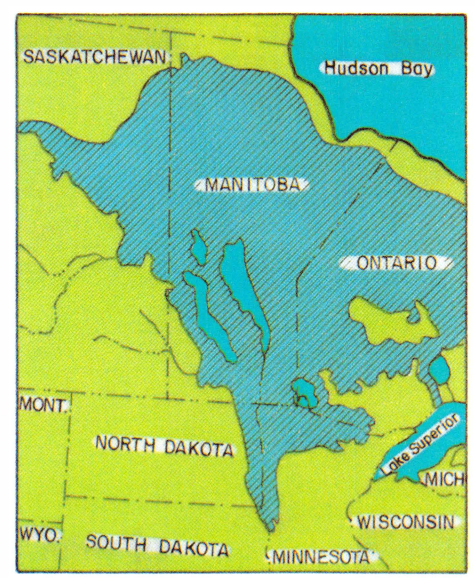
4. North Dakota at the end of the ice age. By 11,000 years ago, most of the active glaciers had melted from the state although in some places large amounts of stagnant ice insulated by a thick covering of debris remained. When the buried ice melted, the overlying materials slumped and slid into hummocky pothole topography. Water that was dammed by the melting ice in the Red River Valley and west of the Turtle Mountains collected in large lakes (Lake Agassiz, Lake Souris, and others). After the ice melted back far enough, blocked drainages were reopened and the lakes drained. Heavy precipitation that continued for some time after the ice had melted caused considerable additional erosion and many of the valleys were deepened.



Schematic drawings of a glaciated eastern North Dakota landscape. The upper diagram illustrates conditions as they may have been about 14,000 years ago, as the ice age came to a close. Several features of a glaciated landscape are shown forming as the ice recedes from the area. The lower diagram shows the post-glacial landscape with some of the landforms that may be seen today.

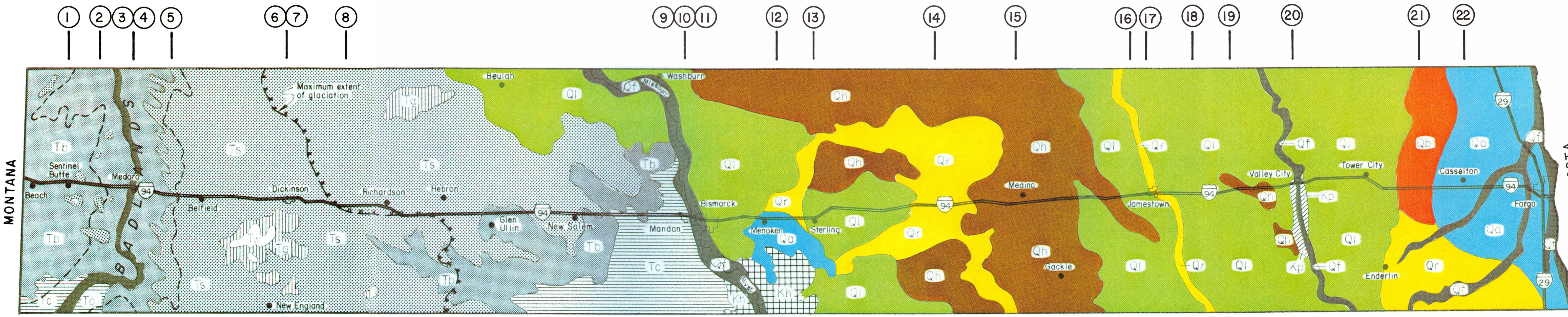
EXPLANATION

		MODERN MATERIALS
Quaternary Period two million years ago until the present	Qf	River floodplain deposits (sand and silt)
		ICE-AGE MATERIALS
	Ql	Glacial deposits with low to rolling relief (till--mixture of sand, silt, and boulders)
	Qh	Glacial deposits with medium to high relief (till--mixture of sand, silt, and boulders)
	Qr	Glacial river deposits with low to high relief (gravel and sand)
	Qa	Lake deposits with low relief (silt and clay)
	Qb	Beach deposits with medium relief (sand)
		PRE ICE-AGE MATERIALS
Tertiary Period 60 million until 30 million years ago	Tw	White River Formation (limestone, clay, and sandstone)
	Tg	Golden Valley Formation (sandy clay, clay, and sandstone)
	Ts	Sentinel Butte Formation (sand, shale, and lignite)
	Tb	Bullion Creek Formation (sand, shale, and lignite)
	Tc	Cannonball Formation (sand, silt, and shale)
Cretaceous Period 80 to 60 million years ago	Kh	Hell Creek Formation (sandstone and mudstone)
	Kp	Pierre Formation (shale)



The area that was flooded by glacial Lake Agassiz is shown by the blue lined pattern. A few of the larger remnants of Lake Agassiz are also shown (solid blue areas). They include Lakes Winnipeg, Winnipegosis, Manitoba, Nipigon, and Lake of the Woods.

The rolling grasslands of eastern North Dakota are a product of glaciation during the ice age. The glaciers deposited thick layers of sediment, which provides soil rich in all the nutrients necessary for fertile farmland.



Description of the Geology Along I-94

ROADLOG

Mileage	Map Number
11	1. Sentinel Butte. The summit of Sentinel Butte is about 4 miles south of the town of Sentinel Butte. To reach the top of the butte, take the left fork in the road about 2 miles south of town (be careful, as the road is sometimes marginal!). At the base of the butte (left side of road) is an excellent exposure of vivid red "scoria" (baked clays) interbedded with layers of white ash. The rocks on top of Sentinel Butte are hard, white, limy claystone. They were deposited in freshwater lakes during mid-Tertiary time about 20 million years ago. Fossil fish have been found on top of the butte, but they are scarce today because the rocks have been thoroughly picked over by collectors. Abundant chalcedony occurs in the gravel near the radio tower on top of the butte.
18	2. Buffalo Gap. This U.S. Forest Service campground is an excellent place to stop and examine a typical mixed-grass prairie environment.
	3. Theodore Roosevelt National Park. The traveler who has time will find it worthwhile to visit Theodore Roosevelt National Park. The scenic badlands in the park formed in a semi-arid climate. Occasional heavy rains, coupled with a lack of vegetation, caused rapid erosion of relatively soft sediments. Resistant layers of harder sandstone or scoria (the reddish layers) cap many of the buttes. The black bands are lignite coal. The sediments that can be seen from the overlook are mainly gray sandstone of the Paleocene age Sentinel Butte Formation, about 60 million years old. A few miles to the west, the sediments of the slightly older Bullion Creek Formation are more yellowish. Notice the many pieces of petrified wood formed when stumps and logs were buried beneath beds of silt and clay and the wood cells were replaced by minerals. The trees that formed the petrified wood were similar to Sequoia trees found in California today.
24	Little Missouri River.
	4. Burning coal veins. Buried layers of lignite coal periodically catch fire and burn, some of them for many years. As the lignite slowly burns, the overlying materials slump down and collapse. Considerable heat and some smoke and fumes are given off during the burning process. Lignite veins in this area burned during prehistoric times, baking and fusing the overlying materials to a reddish-brown color. The resulting material is locally referred to as "scoria," but true scoria is a volcanic rock. Lignite veins may be ignited by prairie fires or lightning and, once started, they can burn for long periods of time.
33 to 38	5. Fryburg Oil Field. Oil is being produced from rocks of Pennsylvanian and Mississippian age (315 to 340 million years old) in the Fryburg Oil Field. The 50 or so wells in this field (not more than one well for every 160 acres) average about 9,000 feet deep. North Dakota has about 3,000 producing oil wells and currently (1983) ranks ninth in the United States among the oil-producing states.
55 to 61	6. Dickinson Oil Field.
	7. Dickinson's economy is closely tied to the oil industry. Several drilling companies and oil-field supply companies are located here. Other geology-related industries in the Dickinson area include the manufacturing of clay products, lignite briquettes, and a brick plant in Hebron.
119	8. Glacial erratics. At the rest area 12 miles east of Glen Ullin, notice the boulders (erratics) that have been gathered from nearby fields. These boulders are rounded from traveling inside the glacier from central Canada. They are "igneous" (fiery) rocks because they formed when hot molten material cooled and solidified inside the earth (much like lava cools and solidifies outside of volcanoes today).
	9. Glacial compared with non-glacial topography. Notice the striking change in the shape of the land east of the Missouri River compared to the land to the west. Immediately east of the Missouri River the landforms resulted from the action of glacial ice about 30,000 years ago and west of the river the landforms are the result of non-glacial processes (wind and running water) that have been operating since at least 100,000 years ago when glaciers last covered that area. Glacial erratics are found on both sides of the river, but west of the river they are the only evidence that remains of glaciation. The erosional topography west of the river consists of large, widely spaced hills and valleys. East of the river, the glacial features are smaller and more closely spaced. The westernmost limit of glaciation along Interstate Highway 94 is actually 50 miles west of the Missouri River, but the area west of the Missouri River was glaciated so much longer ago that the only evidence remaining is the presence of a few glacial erratics (see note 8).
154	10. American Oil Company Refinery. North of the highway at the west edge of Mandan, this refinery processes much of the oil produced in North Dakota.
152 to 158	11. Missouri River Valley. The eastbound traveler can stop at a rest area just west of Mandan and view the Missouri River Valley in which the cities of Bismarck and Mandan are situated. This large valley was cut during the ice age when the glacier dammed the many streams that flowed northeastward at that time. As a result, all the water in the streams, along with meltwater from the glacier, was diverted southeastward along the edge of the glacier and the Missouri River Valley was cut.
169 to 176	12. McKenzie lake plain. The flat area around Menoken and McKenzie is an old lake floor that formed when water was dammed in front of the glacier. At the time the lake flooded this area, the glacier covered much of eastern and northern North Dakota and the edge of the glacier stood a few miles east of McKenzie. When the lake drained, the silt and clay layers that had been deposited in the still water were exposed. Lake sediment commonly results in flat topography because the water-lain silt and clay fills in low areas that were present before the land was flooded.
180	13. Older glacial topography compared with younger glacial topography. Sterling marks the approximate boundary between an older, more subdued glacial landscape to the west and a younger, more rugged glacial landscape to the east. The main reason for the difference in relief is that erosion has been going on for a much longer period of time in the older area, probably about 30,000 years. To the east, where erosion has been in progress only about 10,000 years, the hills that were deposited by the glacier have not yet been worn down appreciably.
207 to 221	14. Kidder sand plain. The land for several miles around Tappen and Dawson is flat in places, rolling in other places, and everywhere the surface is covered by sand. The sand was deposited by streams that flowed on top of glacial ice which, when it eventually melted, resulted in collapse of the overlying materials. Drainage is poorly developed in the area and water flows only to the many potholes. Some of the small lakes are quite salty. White deposits of salt such as sodium sulphate can be seen on many of the lake bottoms when they are dry.
180 to 245	15. Dead-ice moraine. The area from Crystal Springs to Cleveland is dead-ice or "pothole" moraine that formed when thick layers of glacial debris--sand, silt, clay, gravel, and boulders--lying on top of the glacial ice slumped down as the ice melted. Notice the large depressions, such as the one in which the town of Medina is located. Depressions such as this one formed where large blocks of ice melted, allowing the overlying sediments to collapse. In general, depressions resulted where the ice was thick, hills where it was thin.
245 to 319	16. Ground moraine. The area shown in green on the roadlog is nearly flat ground moraine that formed beneath the moving glacier. It is surfaced mainly by till, a mixture of boulders, gravel, and sand in a groundmass of silt and clay. The till is generally quite firm and compact because the ice packed it as it moved over it. The ground moraine is modified in places by meltwater trenches such as the James and Sheyenne River Valleys. Between Tower City and Jamestown several meltwater trenches of various sizes cross Interstate Highway 94.
258	17. James River Valley. The highway crosses the James River Valley at Jamestown. The James River flows south in a large trench that was cut during the ice age by glacial meltwater. When the water flowed at its maximum discharge, the valley was full to both banks resulting in a river as large as the present-day lower Mississippi River.
271	Meltwater trench.
273	Meltwater trench.
275½	18. Continental divide, elevation 1,490 feet above sea level. The area east of the divide is drained by the Sheyenne River and the Red River of the North to Hudson Bay. West of the divide, drainage is southward to the Gulf of Mexico via the James and Missouri Rivers.
278	Meltwater trench.
283	19. Ice-thrust hills. The prominent hills south of the highway at mile 283 consist of materials that were thrust (shoved) by the glacier. Some of the ice-thrust hills in this area are adjacent to lakes that flood the depressions from which the materials in the hills were excavated by the glacier.
290 to 295	20. Sheyenne River Valley. The highway crosses the Sheyenne River Valley at Valley City. This valley, like the James River Valley, was eroded during the ice age by a huge river of glacial meltwater. Many valleys in North Dakota, which were eroded by meltwater, today contain only small streams that are far too small to have formed such large valleys.
305	Meltwater trench.
309	Meltwater trench.
313	Meltwater trench.
319 to 325	21. Beaches. Several beaches of the glacial Lake Agassiz occur in this area.
	Although they are not conspicuous from the road, the beaches can be observed as step-like rises toward the west. They mark former shorelines of Lake Agassiz and they extend north-south for several hundred miles. Like modern beaches, they are composed mainly of sand and gravel.
325 to Red River	22. Agassiz lake plain. The very flat land from Fargo west to mile 325 is the lake floor that remained when glacial Lake Agassiz drained. Lake Agassiz was named after a Swiss zoologist, Louis Agassiz, whose research during the last century popularized the idea of the ice ages. At the time it flooded this area, between about 12,000 and 8,500 years ago, Lake Agassiz occupied the eastern tenth of North Dakota, northern and northwestern Minnesota, much of southern Manitoba, and parts of northwestern Ontario and central Saskatchewan.