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THE GEOLOGY OF NORTH DAKOTA

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INTRODUCTION

The geology of North Dakota is comparatively simple. The geological formations are not as numerous or of such great variety as in many states, and the strata have undergone but little deformation since they were deposited. They are for the most part practically horizontal or have only a gentle dip. Metamorphism has produced little or no change in the rocks, and, except for the deeply buried granite near the eastern borders of the state, there have been no intrusions or extrusions of igneous material. The rocks are chiefly clays, shales, and sandstones belonging to the Cretaceous and Tertiary periods, overlain in most places by the drift deposits of the Pleistocene. The surface features of about two-thirds of the state are therefore those of a gently rolling to rough drift plain. The flat lacustrine plain of the Red River Valley occupies a strip 25 to 35 miles wide along the eastern border, while west and south of the Missouri River the drift mantle is too thin to affect the topography to any great extent. This large area beyond the Missouri everywhere shows evidence of long-continued erosion, with its numerous stream valleys, buttes, mesas, and badlands.

THE PRE-CAMBRIAN GRANITE

Many deep wells in the Red River Valley have reached granite, and these show that beneath the drift and older formations the valley is underlain by crystalline rock which is probably of Archean age, though like some of the Minnesota granite it may possibly be Keweenawan. The granite is struck at depths ranging from 255 to 470 feet, and its surface is quite uneven. It is overlain in some places by glacial drift, in others by Cretaceous shale and sandstone, and in the northern portion of the valley by Paleozoic strata.

In going from south to north in the valley the granite has been encountered in wells at various depths as follows: Wahpeton, 470 feet; Moorhead, Minnesota, across the river from Fargo, 365 feet; well 7 miles north of Moorhead, 255 feet; Casselton, 20 miles west of Fargo, 455 feet; Grand Forks, 385 feet; East Grand Forks, Minnesota, 325 feet; University, two miles west of Grand Forks, 425 feet; and Grafton, 40 miles north, 903 feet. The well at Rosenfeld, Manitoba, 14 miles north of the international boundary and 11 miles west of the Red River, reached the granite (or gneiss) at 1,035 feet.[1] In the Soldiers' Home well at Lisbon, a few miles west of the Red River Valley on the Cheyenne River, the granite was struck at 785 feet. The Moorhead well, which was drilled by the city in search of water and gas, is notable on account of the distance it went in the granite, the record being as follows: 220 feet of alluvial and lacustrine silt, 145 feet of bluish and greenish shales, with beds of sand, probably Benton, and 1,385 feet of granite and gneiss, thus reaching a depth of 1,750 feet.[2]

THE PALEOZOIC SYSTEMS

During at least a portion of this era the Paleozoic sea appears to have covered North Dakota, and in its waters were deposited the limestones, shales, and sandstones of the Cambrian, Silurian, and Devonian. Two or more of these systems outcrop not far to the north in Manitoba, to the east in Minnesota, and to the south

[1] G. M. Dawson, "On Certain Borings in Manitoba and the Northwest Territory," *Trans. Royal Soc. Canada*, IV, sec. 4 (1886), 85–91.

[2] Warren Upham, *U.S. Geol. Survey, Mono. No. 25*, 1896, p. 556.

in the Black Hills, but they are in this state deeply buried beneath more recent formations. The Grafton well passed through, beneath 298 feet of drift and Lake Agassiz silt, 605 feet of Paleozoic strata, including 288 feet of shale and sandstone, which has been referred to the Cambrian, and 317 feet of limestone, sandstone, and shale, which are believed to belong to the Ordovician.[1] In the deep well at Grand Forks, 40 miles south of Grafton, only one foot of limestone was found just above the granite, showing a rapid thinning of the formations in this direction, due either to inequality of deposition or to erosion. The Ordovician appears to thicken rapidly toward the north, for while at Grafton, as stated above, it is 317 feet thick, 60 miles north at Rosenfeld, Manitoba, it has increased to 700 feet, and is overlain by 192 feet of Silurian strata.[2] On the other hand, these formations thin out toward the west, and at Morden, 27 miles from Rosenfeld and 15 miles north of the international boundary, the Ordovician and Silurian are absent, as shown from the well record. The Dakota sandstone at Morden rests directly on the Devonian beds. In the Morden well, at a depth of 412 feet, 188 feet of Devonian red and gray shales and a thin layer of porous limestone were penetrated, and strata of this age cover a narrow strip of territory lying just west of the Silurian in Manitoba. It is not unlikely that these Devonian and Silurian strata extend south some distance into North Dakota. In the deep well at the Jamestown asylum 19 feet of limestone was penetrated at the bottom of the wells, at a depth of 1,505 feet. The well at LaMoure, about 40 miles southeast of Jamestown, struck a compact gray crystalline limestone with a pinkish tinge at 1,300 feet, and went 28 feet in this rock, stopping at a depth of 1,328 feet. The age of the limestone struck in these two wells is not known, though it is probably to be referred to the early Paleozoic. During the later Paleozoic the region does not appear to have been an area of deposition and probably remained above the sea also throughout a large part of the Mesozoic, since rocks belonging to the Triassic, Jurassic, and Lower Cretaceous or Comanchean are, so far as known, wanting in the state.

[1] *Ibid.*, p. 77. [2] G. M. Dawson, *op. cit.*

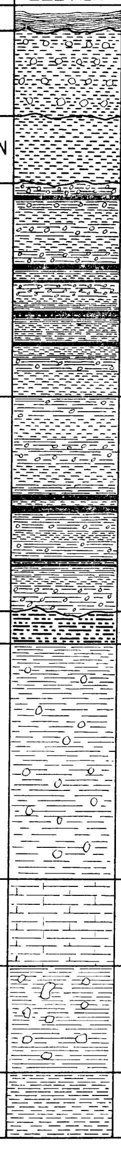
THE CRETACEOUS SYSTEM

Dakota sandstone.—The oldest Cretaceous formation in North Dakota is the Dakota sandstone which is reached in many wells but does not appear at the surface anywhere in the state. In the southeastern counties, as well as in South Dakota and elsewhere, the sandstone is the chief source of artesian water. It is a non-marine formation and was deposited either in a large lake or was spread by rivers over their broad flood plains. The Dakota sandstone underlies the entire state, except a considerable portion of the Red River Valley, where it has been removed by erosion (Fig. 1).

A rather fine-grained white sandstone, which is doubtless the Dakota, is found in a number of wells in the Red River Valley at depths ranging from 250 to 400 feet, and in several wells the sandstone was penetrated 100 feet. In southeastern North Dakota outside the valley, the Dakota sandstone is encountered at depths varying from about 500 feet near the western edge of the Red River Valley to 1,800 feet and over not far west of the James River and near the edge of the Missouri Plateau. The increasing depth of the formation is due both to the westward dip of the Dakota and the rise of the land surface in that direction. The depth of the sandstone at Enderlin is 640 feet; Valley City, about 800 feet; Oakes, 880 feet; Ellendale, 1,035 feet; and Jamestown, 1,450 feet. The deep well at Devils Lake, in the northeastern part of the state, struck the sandstone at 1,431 feet, while at Leeds, 30 miles northwest of Devils Lake, it lies at a depth of 2,110 feet. The Harvey well, near the center of the state, reached the Dakota at 2,235 feet, and a deep boring a few miles from Westhope, Bottineau County, entered the sandstone at about 2,100 feet. Though the well at Mandan reached a depth of 2,000 feet it failed to strike the Dakota, probably by several hundred feet.

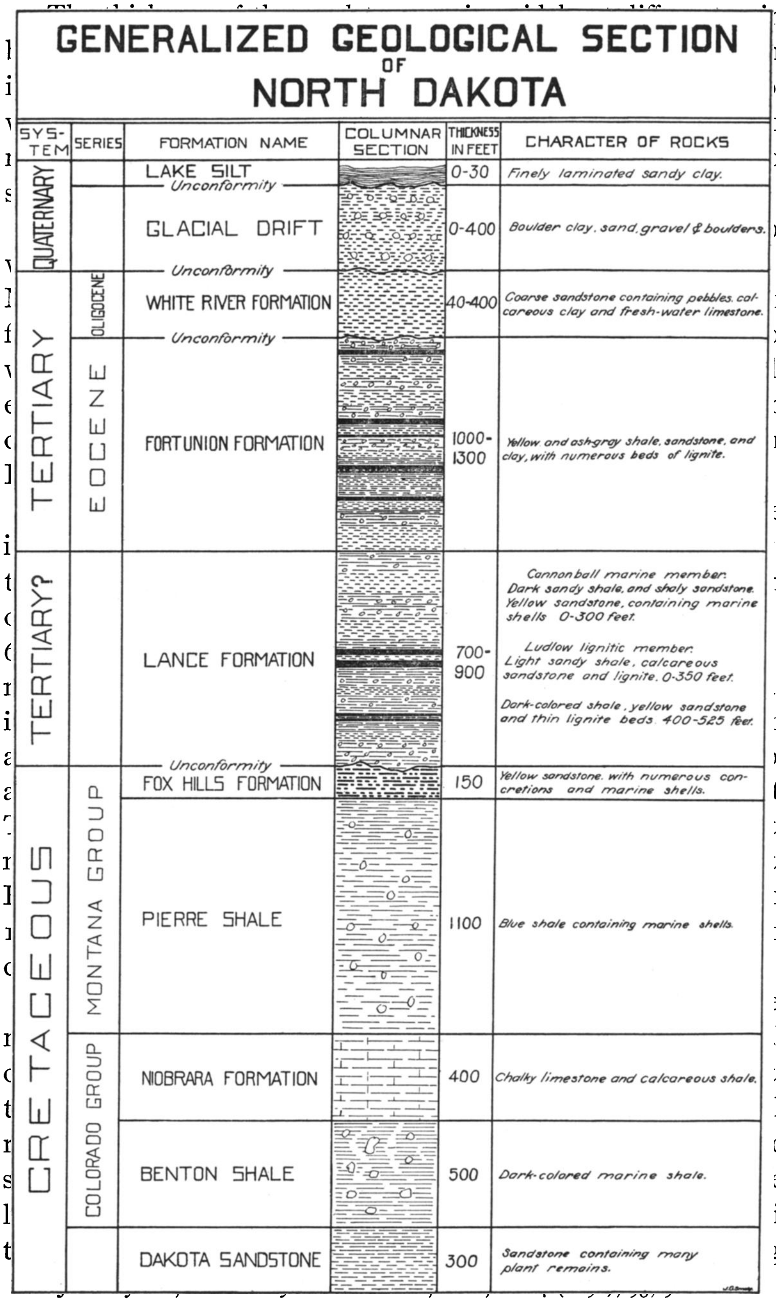
As disclosed by the wells which penetrate it, the Dakota formation is a soft white or gray sandstone in beds 10 to 50 feet thick, separated by shale. In the regions where it occurs at the surface the sandstone has yielded an abundance of fossil leaves, the Dakota flora including no less than 450 species of trees and other plants.

GENERALIZED GEOLOGICAL SECTION OF NORTH DAKOTA



SYSTEM	SERIES	FORMATION NAME	COLUMNAR SECTION	THICKNESS IN FEET	CHARACTER OF ROCKS
QUATERNARY		LAKE SILT		0-30	*Finely laminated sandy clay.*
		Unconformity			
		GLACIAL DRIFT		0-400	*Boulder clay, sand, gravel & boulders.*
		Unconformity			
TERTIARY	OLIGOCENE	WHITE RIVER FORMATION		40-400	*Coarse sandstone containing pebbles, calcareous clay and fresh-water limestone.*
		Unconformity			
	EOCENE	FORTUNION FORMATION		1000-1300	*Yellow and ash-gray shale, sandstone, and clay, with numerous beds of lignite.*
TERTIARY?		LANCE FORMATION		700-900	*Cannonball marine member. Dark sandy shale, and shaly sandstone. Yellow sandstone, containing marine shells 0-300 feet. Ludlow lignitic member. Light sandy shale, calcareous sandstone and lignite. 0-350 feet. Dark-colored shale, yellow sandstone and thin lignite beds 400-525 feet.*
		Unconformity			
CRETACEOUS	MONTANA GROUP	FOX HILLS FORMATION		150	*Yellow sandstone with numerous concretions and marine shells.*
		PIERRE SHALE		1100	*Blue shale containing marine shells.*
	COLORADO GROUP	NIOBRARA FORMATION		400	*Chalky limestone and calcareous shale.*
		BENTON SHALE		500	*Dark-colored marine shale.*
		DAKOTA SANDSTONE		300	*Sandstone containing many plant remains.*

FIG. 1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0-30
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Boulder clay, sand, gravel & boulders.
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OLIGOCENE
WHITE RIVER FORMATION
40-400
Coarse sandstone containing pebbles, calcareous clay and fresh-water limestone.
Unconformity
EOCENE
FORT UNION FORMATION
1000-1300
Yellow and ash-gray shale, sandstone, and clay, with numerous beds of lignite.
TERTIARY?
LANCE FORMATION
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Cannonball marine member. Dark sandy shale, and shaly sandstone. Yellow sandstone, containing marine shells 0-300 feet.
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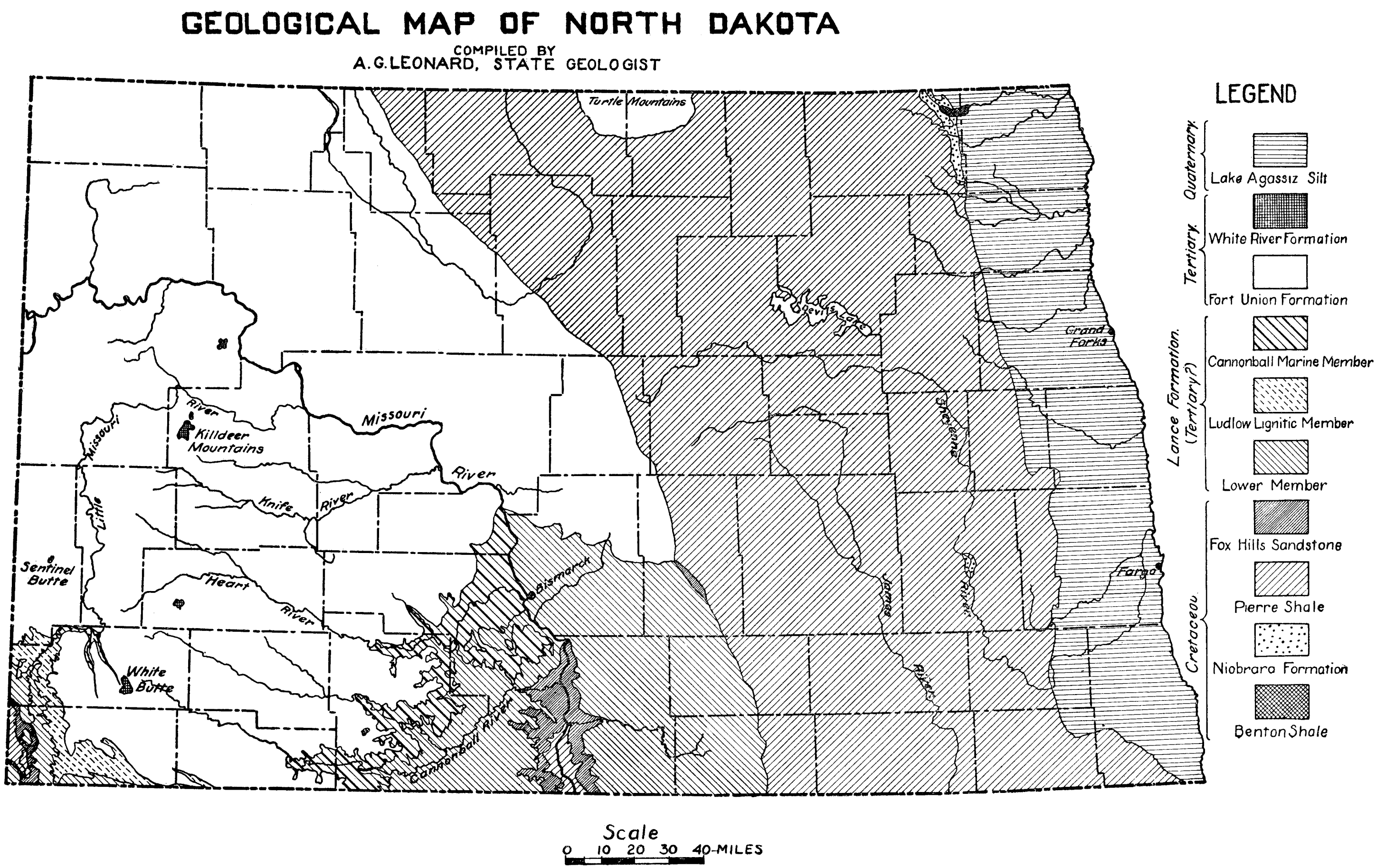
GEOLOGICAL MAP OF NORTH DAKOTA
COMPILED BY
A. G. LEONARD, STATE GEOLOGIST
LEGEND
Quaternary.
Lake Agassiz Silt
Tertiary.
White River Formation
Fort Union Formation
Lance Formation. (Tertiary?)
Cannonball Marine Member
Ludlow Lignitic Member
Lower Member
Cretaceou.
Fox Hills Sandstone
Pierre Shale
Niobrara Formation
Benton Shale
Turtle Mountains
Devils Lake
Grand Forks
Fargo
Sheyenne
River
James
River
Missouri
River
Killdeer Mountains
Knife
River
Heart
River
Little
Missouri
Sentinel Butte
White Butte
Bismarck
Cannonball River
Scale
0 10 20 30 40-MILES

FIG. 2

from 200 to 600 feet or more. In northeastern South Dakota wells have encountered 400 to 480 feet of Benton.

While the Cretaceous formations have been largely removed by erosion from the Red River Valley, a dark-colored shale overlying a soft sandstone has been encountered in a number of wells in different parts of the valley, and it seems not improbable that this is the Benton shale. In that case this shale underlies the drift over a portion of the valley.

Niobrara formation.—Overlying the Benton, the upper member of the Colorado group is present in the wooded escarpment known as the Pembina Mountains, which border the Red River Valley on the west, in eastern Cavalier County. This escarpment extends far to the north in Canada, and the formation appears in the Tiger Hills, Riding and Duck mountains, and the Pasquia Hills. In North Dakota the Niobrara occupies a narrow belt extending 30 miles south of the international boundary, the outcrops being found along the Pembina, Tongue, north fork of Park River, and tributaries of these streams, which have cut deep valleys in the escarpment and exposed the Niobrara beneath the Pierre shale. A highly calcareous shale exposed in the valley of the Cheyenne River at Valley City is also probably to be referred to the Niobrara. It contains 45 per cent of carbonate of lime, and lies just below the black and white bands forming the base of the Pierre, as described on a later page.

The Niobrara is a light to dark gray, moderately hard calcareous shale. It contains numerous small white specks of lime which give it a finely mottled or speckled appearance, plainly seen on fresh fractures. Where the rock has been weathered it becomes almost white and has a chalky appearance; in fact, in many localities outside the state the formation is a nearly pure chalk. Its lime content, which is the most marked characteristic of the Niobrara, is due almost entirely to the presence of minute Foraminifera which are readily seen under the microscope. The most abundant forms are the two species so common in chalk, *Globigerina cretacea* and *Textularia globulosa.* The fact that these Foraminifera are mingled with clay is evidence that the sea in which they lived was not clear, but contained more or less fine sediment and the shells settled to the bottom along with the clay to form the calcareous shale or chalky marl of this Cretaceous deposit.

The percentage of lime carbonate in the different layers varies widely, ranging from 30 per cent and less to 75 per cent. Many of the beds are suitable for making natural hydraulic cement and are used for this purpose, while certain layers have almost or quite the composition of a natural Portland cement rock.

Wherever the Niobrara formation is exposed in the Pembina Mountains it maintains a fairly uniform character throughout its thickness of 150 feet and more. By far the greater portion of the aggregate thickness is formed of a rather dark bluish-gray speckled rock, which commonly varies in lime carbonate content from 55 to 65 per cent in passing from one layer to another. Generally the more speckled the rock appears the higher it is in lime. Between these thicker beds high in lime carbonate are others much thinner, varying from a few inches to a foot in thickness, which are much lower in lime.

Where exposed in northeastern North Dakota the Niobrara strata have yielded a number of vertebrate and invertebrate fossils. Among the latter are *Inoceramus labiatus*, specimens of *Ostrea* and *Avicula*, besides the microscopic forms previously mentioned. The large diving bird, *Hesperornis*, several species of fishes, *Plesiosaurus*, and the vertebrae of a crocodile have also been found.

The maximum thickness of the Niobrara in the Pembina Mountains is 165 feet. At Morden, Manitoba, the formation is 160 feet, and farther north it averages from 150 to 200 feet, but seems to thicken toward the west, for the well at Deloraine, a few miles north of the Turtle Mountains, shows a thickness for the Niobrara of 545 feet. The formation probably has a thickness of at least 400 feet in southern and central North Dakota, since at Valley City the combined thickness of the Benton and Niobrara is about 900 feet. The artesian wells at this place reach the Dakota sandstone at a depth of approximately 800 feet below the bottom of the Cheyenne Valley, and the calcareous shale, which outcrops in the sides of the valley and is believed to be Niobrara, rises about 80 feet above the well curbs. The thickness of the beds between the top of the Dakota sandstone and the base of the Pierre is thus about 900 feet at this point, and the Niobrara probably includes 300 to 400 feet of the section.

Pierre shale.—The Pierre shale occupies most of the eastern half of North Dakota west of the Red River Valley. It also outcrops along the valley of the Missouri River for a distance of over 20 miles north of the South Dakota line, and is brought to the surface in the southwestern corner of the state by the Cedar Creek anticline, which lies mostly in Montana. Throughout the large eastern area it is covered by glacial drift, except where the streams have cut through this mantle and exposed the shale beneath. The Pierre outcrops in many places along the James and Cheyenne rivers and is finely exposed along the South Branch of Park River and other tributaries of the Red River in the region of the Pembina Mountains. The escarpment of the Pembina Mountains is composed largely of this shale, which is well shown in the numerous ravines and gorges, while in places the underlying Niobrara is also seen. The base of the Pierre as found in this region is composed of black, jointed, carbonaceous shales which contain many thin layers of yellow or white non-plastic clay, which has much of the consistency of cheese. The black and yellow strata present a striking appearance and seem to be characteristic of the base of the Pierre over extensive areas. They appear at frequent intervals for a distance of 30 miles along the Pembina Mountain escarpment and extend at least 250 miles northwestward in Canada, where they have been noted in the Riding and Duck mountains. They are also found 130 miles south of the Pembina Mountains at Valley City. The yellow or white clay seams vary in thickness from 1 to 6 inches, and the interstratified black layers from 8 to 14 inches. The uniformity and extent of some of the yellow seams are remarkable because they have been traced continuously for a distance of 35 miles, and a single clay seam 2 inches thick for 25 miles.

The typical Pierre overlying these basal beds is a bluish-gray to dark gray jointed shale of remarkably uniform character, which often weathers into small flaky fragments. The rock commonly shows yellow spots or stains of iron oxide. Erosion has removed the upper part of the formation over most of the large eastern Pierre area, but the topmost beds, where exposed in the southwest corner of the state, contain numerous calcareous concretions varying in size from a few inches to 6 and 8 feet in diameter. Many of these are rich in marine shells, including the following: *Scaphites nodosus* Owen vars. *brevis* and *plenus*, *Anisomyon patelliformis* M. and H., *Inoceramus cripsi* var. *barabina* Morton, *Avicula linguæformis* E. and S., *Ostrea pellucida* M. and H., *Chlamys nebrascensis* M. and H., *Yoldia evansi* M. and H., *Nucula cancellata* M. and H., *Lucina occidentalis* Morton, *Protocardia subquadrata* E. and S., *Callista deweyi* M. and H., and *Nautilus dekayi* Morton.[1]

Below the upper beds of the Pierre, fossils are found only sparingly, those which do occur being *Baculites ovatus* Say, *Scaphites nodosns* Owen, and *Inoceramus sagensis* Owen.

The position of the western boundary of the large Pierre area is known only approximately, since the region is heavily drift-covered and there are practically no outcrops. Not far west of the boundary as represented on the map (p. 7) Fort Union lignite beds are known to occur, so that the Pierre shale is believed to disappear beneath the overlying Fort Union about as shown. It will be noted that no areas of Fox Hills or Lance are represented on the map along most of the margin of the Pierre shale. These formations are not known to underlie the drift farther north than indicated on the map, and in the absence of information regarding their presence in the central and northern parts of the state they are not mapped in that region. If they are actually absent from that area it would of course mean an unconformity between the Pierre and the overlying Fort Union.

The Pierre is the thickest Cretaceous formation in North Dakota, reaching 1,000 to 1,100 feet or over. It is not likely that its entire thickness is represented throughout most of the large eastern area, since the formation had undergone great erosion before being covered by the glacial drift and hundreds of feet were doubtless removed in many places. The aggregate thickness of the Benton, Niobrara, and Pierre is considerably greater in North Dakota than in northeastern South Dakota. In the latter region the aggregate thickness of these formations ranges from 700 to 900 feet, but they become thicker to the north and northwest, where

[1] Identified by Dr. T. W. Stanton.

they reach from 1,300 to about 2,235 feet. At Jamestown they are 1,330 feet thick, at Devils Lake, 1,403 feet, Leeds, over 2,000 feet, and at Harvey they are not far from 2,235 feet thick. The deepest well in the state, at Max, 30 miles south of Minot, has a depth of about 2,400 feet, but it passed through drift, some Fort Union, and probably the Lance before entering the Cretaceous shales, and it did not reach the Dakota sandstone. The Deloraine well not far north of the international boundary went through 1,800 feet of shales, including some Fort Union strata, without reaching the Dakota.

Fox Hills sandstone.—This upper member of the Montana group is known to outcrop in three separate areas in North Dakota. The largest of these is along the Missouri River, where the formation is exposed for over 40 miles north of the South Dakota line and extending 5 to 10 miles on either side of the river. A narrow belt of Fox Hills sandstone surrounds the Pierre area in the southwestern corner of the state, and there is a small outcrop near the center of the state.[1]

The Fox Hills is particularly well shown along the Cannonball River for a distance of over 12 miles above its mouth, where the sandstone forms vertical cliffs rising from 80 to 90 feet above the river and is overlain by banded shale. The sandy portion of the formation is a yellow, rusty brown or gray, rather soft sandstone. Cross-bedding is very common, and the formation contains great numbers of large and small ferruginous sandstone concretions and indurated masses and layers, these also exhibiting cross-bedding. The concretions are apparently due to the segregation of the iron in certain portions of the rock, cementing the sand into firm, hard masses, considerably harder than the sandstone in which they are imbedded. These concretionary masses vary in size from an inch and less to 6 and 8 feet. Small, irregular, twisted or stemlike forms are abundant in places. Some portions of the rock are so completely filled with these rusty brown concretions that they constitute the main bulk of the formation, and the gray, loosely cemented sandstone forms a kind of matrix, in which the harder concretions are imbedded. In the process of weathering these

[1] Described by Dr. T. W. Stanton in a letter to the writer.

more resistant masses project beyond the softer rock, and at the base of slopes and scattered over the surface they are exceedingly abundant. Many of the concretions are spherical in shape and of good size, and it is these which have given the name to the Cannonball River, since they occur abundantly along that stream.

In the southwestern area in Bowman County the Fox Hills is composed of 60 feet of massive gray sandstone, which weathers to a yellow color, and below this is 25 feet of sandy clay formed of light and dark laminae.

Marine fossils are quite abundant in the Fox Hills sandstone, and the following are among those found in the Missouri River area and identified by Dr. T. W. Stanton: *Tancredia americana* M. and H., *Callista deweyi* M. and H., *Ostrea pellucida* M. and H., *Avicula linguiformis* E. and S., *Avicula nebrascana* E. and S., *Protocardia subquadrata* E. and S., *Tillina scitula* M. and H., *Mactra warrenana* M. and H., *Scaphitis cheyennensis* (Owen) and *Chemnitzia cerithiformis* M. and H.

The Fox Hills in North Dakota ranges in thickness from 85 to about 200 feet, with an average of about 150 feet.

CRETACEOUS OR TERTIARY SYSTEM

Lance formation.—As shown on the geologic map (p. 7) this formation occupies a considerable area on either side of the Missouri River in south-central North Dakota, and a smaller area in the extreme southwestern corner of the state. The beds are well exposed in the bluffs of the Missouri, particularly on the west side of the river 15 to 20 miles below Bismarck, and in many places along the Cannonball and Heart rivers. The bluffs and badlands of the Little Missouri in Slope and Bowman counties also afford many excellent outcrops.

As shown by Lloyd,[1] the Lance formation in south-central North Dakota consists of a lower portion of shale and sandstone beds of continental origin, and an upper member of sandstone and shale of marine origin which is known as the Cannonball marine member. Farther west in Slope and Bowman counties the upper member of

[1] E. R. Lloyd, "The Cannonball River Lignite Field, North Dakota," *U.S. Geol. Survey, Bull. No. 541*, 1914, p. 249.

the Lance is non-marine and lignite-bearing and has been named the Ludlow lignitic member.[1] The Cannonball marine and Ludlow lignitic members occupy similar stratigraphic positions and are believed to be contemporaneous in age.

The lower part of the Lance is best exposed in the badlands bordering the Little Missouri River in Bowman and Slope counties, where it is composed of shales alternating with soft gray or yellow sandstones, the beds having a notably dark and somber aspect. The prevailing colors are dark gray, but beds of brown carbonaceous shale are common and conspicuous. Much dark brown ferruginous material is present, occurring both in thin seams and concretions, the latter being most numerous at certain horizons, and fragments of this cover the slopes in many places. Another characteristic is the great number of sandstone concretions, some small and others 8 to 10 feet in diameter. Only occasional thin seams of lignite are found in the lower part of the Lance.

The Ludlow lignitic member in North Dakota is similar lithologically to the lower part of the Lance except that numerous beds of lignite are present. In western Slope County it contains at least 5 lignite beds which are from 4 to 30 feet in thickness.

The flora of both the lower part of the Lance and the Ludlow lignitic member is similar to that of the overlying Fort Union, the great majority of the species being common to both formations, according to Knowlton.[2] The Lance thus has a Fort Union flora. The characteristic vertebrate fossils of the Lance are the three-horned dinosaur *Triceratops*. *Trachodon* bones are also present in these beds.

The Cannonball marine member has been mapped only west of the Missouri River, and while, in the absence of outcrops, it is not represented on the geologic map as occurring east of the river, it seems not unlikely that it may be present beneath the drift, and that a portion of the area mapped as the lower member of the Lance is occupied by the Cannonball marine member. On account of

[1] E. R. Lloyd and C. J. Hares, "The Cannonball Marine Member of the Lance Formation of North and South Dakota and Its Bearing on the Lance-Laramie Problem, *Jour. Geol.*, XXIII (1915), 523–47.

[2] *Proc. Wash. Acad. Sci.*, XI (1909), 218–24.

the heavy covering of drift the eastern boundary of the area is probably only approximately correct.

Not only is the Cannonball marine member well exposed along the river from which it is named, but it is also well shown in many outcrops along the Heart River in the vicinity of Mandan and in the bluff of the Missouri near Bismarck. It is composed of dark gray to black shale, arenaceous in part, with a subordinate amount of gray and yellow sandstone. Some thin beds of limestone are also present.

After the deposition of the Fox Hills sandstones the Cretaceous sea withdrew from the region for a time and the beds constituting the lower part of the Lance were formed. These and the Ludlow lignitic member of the western area are of continental origin and were probably formed in part by rivers, though much of the formation may be of lacustrine origin. As the lakes were filled with sediment, they were converted into swamps in which trees and other vegetation grew and accumulated year after year to form the beds of lignite which are characteristic of the upper non-marine portion of the Lance. But while this Ludlow lignitic member was being deposited to the west the sea again entered the region, perhaps from the east, and in its waters were formed the Cannonball marine member, with its abundant fauna of marine shells, which Dr. Stanton characterizes as a modified Fox Hills fauna.[1] That this sea may have extended westward almost to the Montana line is suggested by the occurrence in the Little Missouri badlands of western Slope County of a bed containing *Ostrea glabra* and *Ostrea subtrigonalis*. Since these oysters are brackish-water forms the open sea was probably not far distant, and the shale bed containing them appears to be the westward extension of the Cannonball marine member. The zone in which the shells are found lies 120 feet below the top of the Ludlow lignitic member. Following the deposition of the Cannonball marine member the sea withdrew from the region never to return again.

The thickness of the Lance formation along the Little Missouri is about 820 feet, the upper 300 feet representing the Ludlow lignitic member. In the Cannonball River region the Lance is about 700 feet thick.

[1] E. R. Lloyd and C. J. Hares, *op. cit.*, p. 537.

The relation of the Lance formation to the underlying Fox Hills is of importance as bearing on the age of the former. In many localities in Wyoming, Montana, and South Dakota, where the contact has been observed, the Lance rests unconformably on the Fox Hills. On Little Beaver Creek in northwestern Bowman County the Fox Hills sandstone had undergone erosion before the deposition of the Lance beds, and although it has been questioned whether this erosion represents a long time interval, the relationship elsewhere suggests the probability that the unconformity here may represent a considerable interval.

Lying as it does on the border line between the Cretaceous and Tertiary, with its Fort Union (Tertiary) flora and its vertebrate fauna of Mesozoic types, the age of the Lance formation is still undetermined. Some would place it in the Tertiary while others would include it with the Cretaceous on account of its dinosaurs and other Mesozoic forms.

TERTIARY SYSTEM

Fort Union formation.—Overlying the Lance and resting in some places on the Cannonball marine member, in others on the Ludlow lignitic member, is the Fort Union formation. Deposition went on without interruption from the beginning of Lance time to the close of Fort Union time, during which over 1,800 feet of sediments accumulated, all of continental origin except those of the Cannonball marine member.

The Fort Union formation, which covers the greater part of western North Dakota, contains most of the lignite deposits of the state, the lignite beds of the Lance being relatively unimportant. Outcrops are abundant in the Little Missouri badlands, as well as along the Missouri and other streams of the region, and these extensive outcrops afford exceptional opportunity for the study of the formation. The Fort Union is remarkably uniform in color, composition, and general appearance over many thousands of square miles. It is composed of shales alternating with soft sandstone and contains numerous beds of lignite. The prevailing colors are light ash gray and yellow, but some layers are nearly white.

One of the most conspicuous features of the Fort Union is the vast quantity of baked and fused rock, or clinker, produced by the heat of the burning lignite beds. The overlying shales and sandstones have been burned to a red or pink color and in places completely fused to slaglike masses. This clinker caps many of the ridges and buttes of the region, having protected them from erosion by its superior hardness. The beds of clinker vary in thickness from 5 or 6 to 40 feet and over, the thicker masses probably having been produced by the burning of several lignite beds and the baking of the intervening shales, all now forming a single bed.

The Fort Union everywhere contains numerous beds of lignite. These vary in thickness from an inch and less to 35 feet, beds 6, 8, and 10 feet thick being common. Many of the lignite beds cover large areas. One with a thickness of from 5 to 16 feet has a known extent of 20 miles in one direction and 25 in another, thus covering an area of at least 500 square miles. Another is known from its outcrops to have an area of over 900 square miles, and its probable extent is from 1,000 to 1,500 square miles. This bed ranges in thickness from 9 to 15 feet and over. The lignite is found from top to bottom of the Fort Union, and since it is present also in the upper part of the Lance formation it has a vertical range of from 1,200 to 1,300 feet.

The Fort Union, which is Lowest Eocene, or Paleocene, in age, contains an abundant flora, about 300 species of plants having been described from this formation. It has a fauna comprising both fresh-water shells and vertebrates. Among the former are *Unio priscus* M. and H., *Viviparus trochiformis* M. and H., *Viviparus leai* M. and H., *Viviparus retusus* M. and H., *Campeloma multilineata* M. and H., *Campeloma producta* White, and *Corbula mactriformis* M. and H. Among the vertebrate remains are fishes, turtles, the aquatic reptile *Champsosaurus laramiensis*, and mammalian teeth.

A large part of the Fort Union formation has been removed by erosion and only in the higher buttes and divides of western North Dakota has the upper part been preserved. In Billings and Golden Valley counties it has a thickness of 1,000 feet, while farther north, in McKenzie County, the formation reaches 1,300 feet in thickness.

The shales and sandstones of the Fort Union appear to be very largely of lacustrine origin. The channel sandstones and the conglomerates which are present in places at the base of the formation were probably deposited by rivers, as were some of the shales and sandstones above, but the greater part of the sediments appears to have been laid down in lakes, many of them of large size and occupying parts of North Dakota, Montana, South Dakota, Wyoming, and a considerable area in Canada. This region is believed to have been a great flat plain occupied by numerous lakes, and over this plain large sluggish rivers took their meandering course. Thus deposits made on the flood plains of rivers, and wind deposits, are doubtless represented in the Fort Union, along with lacustrine deposits, which make up the bulk of the formation.

Various features characteristic of fluviatile deposits, such as local unconformities and filled channels, are, so far as known, not found in the Fort Union except at the base of the formation, and cross-bedding is of rare occurrence in the sandstones. Were the shales and sandstones of the Fort Union formed chiefly through deposition by rivers the foregoing features should be present, and the fact that except for a little cross-bedding they are not found above the base suggests that the deposits are lacustrine in large part.

The numerous lignite beds of the Fort Union are evidence that the region was occupied again and again by swamps, many covering hundreds and even thousands of square miles. These were probably formed by the partial filling of the lakes with sediment brought in by rivers, thus converting them repeatedly into swamps. The coal-forming vegetation growing in these swamps consisted, as determined by Thiessen,[1] very largely of coniferous trees, including varieties related to the Sequoia, cypress, juniper, and arbor vitae, together with some firs and spruces. The woody material of these trees, including trunks, stems, and branches, comprises roughly 75 to 85 per cent of the whole mass of the lignite. That the vegetation accumulated in some of these swamps for thousands and tens of thousands of years is indicated by the fact that several

[1] David White and Reinhardt Thiessen, "The Origin of Coal," *Bureau of Mines, Bull. No. 38*, 1913, p. 222.

of the lignite beds have a thickness of 20 feet and one of 35 feet. That the coal swamps recurred repeatedly in many parts of the region is proved by the presence in some vertical sections of as many as 15 or 20 lignite beds, the majority of them, it is true, of no great thickness. Among the lakes and swamps there grew many varieties of trees, including, according to Knowlton,[1] the poplar, oak, walnut, fig, elm, maple, birch, alder, dogwood, hickory, box elder, buckthorn, viburnum, witch-hazel, horse chestnut, and bittersweet. Interspersed with these were scattered conifers and ginkgos. Thus during Fort Union time North Dakota and adjoining areas were covered with dense forests. Osborn thus describes the region as it was at this period: "Vast stretches of subtropical and more hardy trees were interspersed with swamps where the vegetation was rank and accumulated rapidly enough to form great beds of lignite. Here were bogs in which bog iron was formed. Amid the glades of these forests there wandered swamp turtles, alligators, and large lizards of the characteristic genus *Champsosaurus*."[2]

White River formation.—The deposition of the Fort Union sediments was followed by a long erosion interval during which hundreds of feet of strata were removed. Erosion was going on during most of the Eocene period, and a well-marked unconformity therefore separates the Fort Union from the overlying White River formation of the Oligocene.

The White River beds occupy a number of small and widely scattered areas west of the Missouri River. It is necessary to exaggerate the size of these areas in order to represent them on the geologic map (p. 7). The formation is especially well exposed in White Butte, in Slope County, where it covers an area of 8 to 10 square miles, forming the highest portion of the divide at the headwaters of the north fork of the Cannonball River and Sand and Deep creeks. It is here composed of white clays at the bottom, on which rests a coarse sandstone filled in places with large pebbles; this is overlain by about 100 feet of calcareous clays, which in turn are overlain by more than 100 feet of fine-grained greenish sandstone. These deposits represent all three members of the White

[1] F. H. Knowlton, *U.S. Geol. Survey, Bull. No. 611*, 1915, p. 59.

[2] H. F. Osborn, *The Age of the Mammals*, p. 100.

River formation, the lower or Titanotherium beds, the middle or Oreodon beds, and the upper or Protoceras beds.

It is probably this area, in what was then Dakota Territory, which was visited by E. D. Cope in 1883, and from it he collected twenty species of vertebrates, including *Trionyx, Galecynus gregarious, Aceratherium, Elotherium ramosum, Oreodon, and Leptomeryx.*

The beds of the White Butte locality have been described in considerable detail by Earl Douglass,[1] and in the middle member, or Oreodon beds, he found the following vertebrate fossils: *Ictops, Ischyromys, Palaeolagus, Merycoidodon culbertsoni, Leptomeryx evansi, Mesohippus, Hyracodon, Gymnoptychus, Eumys,* and *Aceratherium.* Another White River area was discovered by Douglass about 30 miles northeast of White Butte, in western Stark County. All three members of the White River formation are here present and contain mammalian bones.

The 40 feet of calcareous clay and compact, siliceous, thin-bedded limestone occupying a few acres on top of Sentinel Butte, in Golden Valley County, is referred to the White River formation. Seventy miles east of White Butte, in Grant County, the White River formation occurs on the tops of three high buttes. The deposits are briefly described by E. R. Lloyd[2] as consisting of about 50 feet of calcareous sandstone overlying a marly limestone, both being referred to this formation "on faunal and lithologic evidence."

Far to the north of the above-mentioned areas, in the Killdeer Mountains of northwestern Dunn County, there are 400 feet of strata which are so wholly unlike the underlying Fort Union, on which they rest unconformably, that they have been referred to the White River formation. This area has recently been described by T. T. Quirke.[3] The deposits here consist of green or pink non-plastic clays, green friable calcareous sandstones, limestones, and chalklike arenaceous marl. The rocks are similar in character to those of the White River formation found elsewhere in the region, and they undoubtedly belong to that formation.

[1] *Annals of the Carnegie Museum,* V, Nos. 2 and 3 (1909), 281–88.

[2] E. R. Lloyd, "The Cannonball River Lignite Field, North Dakota," *U.S. Geol. Survey, Bull. No. 541,* 1914, p. 251.

[3] T. T. Quirke, "The Geology of the Killdeer Mountains, North Dakota," *Jour. Geol.,* XXVI (1918), 255–71.

About 25 miles north and east of the Killdeer Mountains, in eastern McKenzie County, many of the high buttes are capped with 200 feet of strata resembling those in the Killdeer Mountains. It is believed that the greenish sandstones and greenish clays of these buttes are likewise to be referred to the White River formation.

The strata in all these localities are clearly only remnants of much larger areas which have suffered extensive erosion and only relatively small patches of the White River formation have been left. It is not unlikely that several of those nearest together may formerly have been connected.

The beds of this formation are in part lake deposits and in part river deposits. Those of Sentinel Butte, the easternmost areas in Grant County, and most of the beds of the Killdeer Mountains are doubtless of lacustrine origin, while portions of the deposits of White Butte and the next area to the north are likewise lake deposits. The coarse pebbly sandstones and perhaps other strata were deposited by rivers.

While western North Dakota was an area of deposition in Lowest Eocene or Paleocene time and also during the early part of the Oligocene epoch, nevertheless during most of the Tertiary period the region was undergoing erosion. This resulted in the removal of many hundreds of feet of strata over most of the state, and in places the aggregate thickness of the Cretaceous and Tertiary deposits thus carried away by streams amounted to 1,000 feet and over. The outlier known as the Turtle Mountains, the Fort Union strata of which were once continuous with those of the Missouri Plateau, was during this time separated from the plateau by the denudation of the intervening area. The broad depression of the Red River Valley was cut to a depth of 800 to 900 feet in the Cretaceous and older rocks of eastern North Dakota and Minnesota by a large northward-flowing river. The topographic features of the region west of the Missouri River, including the rolling uplands, the high ridges and divides, the numerous buttes, the escarpments, and badlands, were all formed in large measure by erosion during the Tertiary period, continued, of course, in the Pleistocene.

Since the Cretaceous and Tertiary strata were deposited they have undergone but little deformation, though the region has several times been elevated, in the aggregate to the extent of some

2,000 to 3,000 feet. Only locally has there been warping or folding of the strata, as in the Cedar Creek anticline, which extends from near Glendive, Montana, southeast into southwestern North Dakota.[1] This anticline was probably formed about the close of Fort Union time and prior to the deposition of the White River beds.

QUATERNARY SYSTEM

Pleistocene deposits.—The Cretaceous and Tertiary formations are largely buried beneath a mantle of Pleistocene deposits left by the ice sheets which once covered the region. These deposits conceal the bed rock except where they have been cut through by streams, thus exposing to view the underlying formations. With the exception of the Lake Agassiz silt of the Red River Valley the Pleistocene deposits are not shown on the geologica lmap (p. 7). but they cover the entire state, except the southwest corner. The preglacial surface on which they rest had undergone great erosion during the Tertiary period, as already stated, and was therefore doubtless quite uneven and rough and cut by many stream valleys. These surficial deposits rest on the Archean granite and Paleozoic rocks in the Red River Valley; farther west they rest on the Pierre and other Cretaceous formations, and in western North Dakota they directly overlie the Tertiary strata. They overlie the earlier formations without regard to altitude, the surface on which they rest ranging in elevation from 450 to 2,500 feet above sea-level.

Glacial drift.—The only portion of the state which was not buried beneath the Pleistocene ice sheets, and hence did not receive a deposit of drift, is the southwest corner. The drift extends from 40 to 60 miles west and south of the Missouri River, though it is here represented largely by gravel and bowlders, since the till is thin and in scattered patches.

There are at least two, and probably three, drift sheets in North Dakota, namely, Late Wisconsin, Early Wisconsin, and an older drift, which may be referred to provisionally as the Kansan, though it may prove to be younger. The Late Wisconsin drift covers

[1] A. G. Leonard, *U.S. Geol. Survey, Bull. No. 285*, 1906, p. 317; *No. 316*, 1907, pp. 195, 203; W. R. Calvert, *U.S. Geol. Survey, Bull. No. 471*, 1912, p. 201.

considerably over one-half the state, including the eastern and northwestern portions, and its western border is marked by the wide, massive Altamont moraine, which in places has a width of 20 miles and over. Outside of the Altamont moraine there is in northwestern North Dakota and perhaps elsewhere in the state a drift which is little older than that within the moraine, and is itself marked by occasional morainic patches. This young drift, which in Williams County extends 20 miles or more south of the Altamont moraine, is probably Early Wisconsin. Beyond the Early Wisconsin till and appearing at the surface for the most part west and south of the Missouri River, is a distinctly older drift whose age is not yet definitely determined, but which may be Kansan. This pre-Wisconsin drift has been described elsewhere[1] and need not be discussed more fully here. It forms well-developed moraines in northeastern Morton and northern McKenzie counties.

In marked contrast to the older drift the Wisconsin has suffered very little erosion, its surface is poorly drained, is characterized by almost countless lakes, ponds, swamps, and marshes, and by many rough, hilly, morainic belts. Twelve of these moraines, including the remarkably wide and massive Altamont moraine, have been mapped in eastern North Dakota[2] and adjoining regions.

The drift varies in thickness from a few feet to 300 and even 400 feet, though the latter thickness is probably exceptional. In the Red River Valley the till is commonly from 200 to 300 feet thick, and in other parts of the state covered by Wisconsin drift the thickness appears to be somewhat less, ranging usually from 150 to 250 feet. The pre-Wisconsin drift is much thinner, the maximum thickness so far noted being 100 feet. West of the Missouri River it is seldom as much as 8 or 10 feet and generally not over 2 or 3 feet or less.

Lake Agassiz silt.—In the Red River Valley the glacial drift is in most places covered by a fine silt which was deposited in Lake Agassiz toward the close of the Pleistocene. Associated with this

[1] A. G. Leonard, "The Pre-Wisconsin Drift of North Dakota," *Jour. Geol.*, XXIV (1916), 521–32.

[2] Warren Upham, "Glacial Lake Agassiz," *U.S. Geol. Survey*, *Mono. No. 25*, Plate XVII.

are alluvial deposits spread over the surface by the Red River and its tributaries. This fine, thinly laminated silt commonly has a thickness of 30 to 50 feet, though in places it is considerably less.

Where rivers entered the lake the sediment carried by them accumulated to form delta deposits. Three such deltas are found in North Dakota, the largest, formed by the Cheyenne River, covering an area of about 800 square miles. The sand of this delta has been heaped by the wind into dunes, and a large tract of the delta is covered by these sand hills.

Recent deposits: alluvium.—Alluvium is found along practically all the streams of the state, being deposited by the rivers over their valley bottoms in time of flood, and in some of the larger valleys it has accumulated to a considerable depth. It is composed of sand, clay, and gravel, the upper 2 or 3 feet being commonly clay. The belt of alluvium along the Missouri River averages 2 to 3 miles in width. As shown by borings, the silt deposited by this river reaches in places a thickness of nearly 100 feet. Some of it may have been deposited during the Pleistocene, but much of this alluvium of the Missouri and other rivers belongs to the Recent epoch.

Quaternary history.—In conclusion the course of events during the Quaternary period may be briefly described. At the close of the Tertiary the warmth of a temperate climate gave way to the rigors of an arctic cold. North Dakota was several times invaded by an ice sheet and many of the surface features as we find them today are the result of these invasions, particularly of the most recent one. The ice of the earlier invasion crossed the broad and deep valley of the Missouri and extended from 40 to 60 miles beyond that river. The deposits of this older glacier are in most places thin and appear to have undergone much erosion. This drift west of the Missouri may never have been very thick, except locally, where it forms moraines, and much of the finer material of the till has been swept away by the streams, leaving behind the gravel and bowlders.

This ice invasion produced important changes in the preglacial drainage of the region. The Missouri Valley and the lower valleys of the Yellowstone and Little Missouri rivers were blocked with ice, so that all these streams were forced to seek new channels. Lakes were formed in the valleys of the Yellowstone and Little Missouri rivers, the water rising until it overflowed at its lowest point the divide between the latter and the Knife River. The combined waters of the three rivers flowed east and southeast to the mouth of the Cannonball, where they entered the Missouri Valley. The length of this Pleistocene valley from the head of the Knife to the mouth of the Cannonball is 155 miles. Upon the withdrawal of the ice sheet the Missouri and Yellowstone rivers returned to their former valleys, but the lower valley of the Little Missouri was permanently abandoned and that river took an easterly course from the point where its preglacial course was blocked by the front of the ice sheet.

After the first invasion the climate grew warmer and the glacier retreated northward, so that conditions were probably favorable for the return of animal and plant life. Upon the recurrence of the cold climate the ice sheet again advanced over the region and probably reached about to the Missouri River. Evidence that this second advance crossed the latter stream is lacking, and it is known to have stopped far short of the limits reached by the first invasion. Then after a relatively short interglacial interval, during which the glacier withdrew from the region, there was a third invasion of the ice sheet, coming as before from the center west of Hudson Bay. The limit reached by this Late Wisconsin ice sheet is marked by the Altamont moraine. This remarkably well-developed moraine forms a very rough belt of massive hills and ridges which extends without interruption for hundreds of miles. In places it is fully 20 miles wide and throughout much of its extent in North Dakota its width probably averages 12 to 15 miles. While forming the moraine the ice front doubtless fluctuated back and forth across the belt for a long period.

During its recession the ice sheet halted again and again and thus built a series of moraines. Some of these halts were brief and the resulting moraines poorly defined; others were of much longer duration, as shown by the great amount of material deposited and the large size of the hills and ridges.

Lake Agassiz: The early history of Lake Agassiz, according to Upham,[1] was intimately connected with the recession of the ice front, since when the glacier had retreated across the divide between the Minnesota and Red rivers the lake was formed by the ponding of the water at the south end of the Red River Valley. According to this view, Lake Agassiz began as a small body of water and expanded northward as the ice melted until its maximum was attained, its area at that time being about 110,000 square miles.

Recently W. A. Johnson, of the Canadian Geological Survey, has attributed a different life-history to Lake Agassiz.[2] He believes with Tyrrell that after the retreat of the Keewatin glacier northward into Manitoba there was comparatively free drainage in that direction, so that an earlier glacial marginal lake associated with a lobe of the Keewatin glacier was largely or wholly drained. Lake Agassiz proper did not come into existence until a later advance of the ice from the northeast was met by a slight advance of the Keewatin glacier, which resulted in the ponding of the northward drainage and the initial stage of the lake. The waters gradually rose and extended southward, filling the Red River Valley and overflowing to the south.

It will be noted that these two views differ radically, one holding that the lake began at the upper or south end of the valley and expanded northward with the retreat of the ice margin; the other, that the lake originated well to the north in Manitoba after much of the Red River Valley was already free of ice, and had first a rising stage as it increased in size and extended southward over the valley floor. But in either case Lake Agassiz owed its existence to the presence of the ice barrier to the north and northeast, higher land holding in its waters on the other sides of the basin.

This Pleistocene lake left its mark on the region in the form of beaches, deltas, and lacustrine silts. The gradual retreat of the ice barrier which held the lake in place afforded outlets at different levels, and at many of these stages the water remained long enough to form more or less distinct beach lines. A series of beach ridges

[1] Warren Upham, "Glacial Lake Agassiz," *U.S. Geol. Survey, Mono. No. 25.*

[2] W. A. Johnson, "The Genesis of Lake Agassiz," *Jour. Geol.*, XXIV (1916), 625–38.

were thus formed, the best developed of which commonly rise 10 to 20 feet above the adjoining surface on the side toward the former lake. They are composed of interstratified gravel and sand, and vary in width from 10 to 30 rods.

These beaches afford evidence of the elevation of the land to the north, since they are no longer horizontal, nor are they parallel, but show a divergence among themselves. All have a gradual ascent toward the north or northeast; the upper or Hermon beach, for example, rises 175 feet between Lake Traverse, at the south end of Lake Agassiz, and the international boundary. As these shore lines also show a divergence among themselves it is evident that this upward movement of the earth's crust began while Lake Agassiz was in existence and was probably largely completed before the lake was finally drained.

Sand and gravel deltas, so extensive as to constitute notable topographic features, were formed by the streams that flowed into Lake Agassiz while it stood at its highest stage. Those in North Dakota were formed by the Cheyenne, Pembina, and a Pleistocene river no longer in existence. Much of the finer sediment contributed to the lake by the inflowing streams was carried by the waves and currents and spread over the bottom of the lake as a fine silt. It is this fine loam, mingled with decayed vegetation, which forms the rich black soil of the Red River Valley, one of the great wheat regions of the world.

So recent is it geologically since the last ice sheet withdrew from North Dakota, and since Lake Agassiz was drained, that the drift surface and lake bed have been but slightly affected by erosion, and are still much as they were left at the close of the glacial period.