CHAPTER III.

GEOLOGIC FORMATIONS UNDERLYING THE DRIFT.

Archean, Lower and Upper Silurian, Devonian, and Cretaceous formations succeed each other from east to west as the bed-rocks of the area of Lake Agassiz (Pl. XIV). They will be briefly described here in this order, which is that of their age and superposition, beginning with the oldest and lowest. Throughout large portions of this region, including the whole district drained by the Red River in Minnesota, the underlying rocks are covered by the glacial drift, and afford no outcrops; but their character and approximate boundaries on these tracts are inferred with much probability from the nearest outcrops, from topographic features, from the bowlders and other material of the drift, and from sections shown by deep wells which pass through the drift to the rocks beneath.

Intervening in stratigraphic order between the Archean and Silurian systems are large areas of the Algonkian and Cambrian systems, as mapped on Pl. XIV for the country about the west part of Lake Superior; but the Algonkian and Cambrian rocks probably have no outcrops on the Lake Agassiz area.

ARCHEAN FORMATIONS.

On the east side of the south part of Lake Agassiz a belt of Archean rocks extends from the Minnesota River northeast and north, partly covered west of Lake Superior by the Algonkian formations, through central and northern Minnesota, where it widens into the main area of these rocks in North America. This great Archean area stretches from Labrador and the lower St. Lawrence southwest to Georgian Bay of Lake Huron, west to Lakes Superior and Winnipeg, and thence northwest and north to the Arctic Sea. Its western border was covered by Lake Agassiz from the Lake of the Woods to the north end of Lake Winnipeg.

THE ARCHEAN AREA IN MINNESOTA.

The most southwestern outcrops of Archean formations in Minnesota are 10 to 20 miles southwest of the Minnesota River in Redwood and Yellow Medicine counties, where small isolated exposures of granite, gneiss, and schists occur. The deeply eroded valley of the Minnesota River, channeled by the River Warren, outflowing from Lake Agassiz, cuts through the drift sheet to the bed-rocks, which from Big Stone Lake to Little Rock Creek, 4 miles below Fort Ridgely, are Archean gneisses, varying from a granitoid to a schistose structure. In the next 13 miles no rocks older than the Cretaceous are found. Then comes the last Archean outcrop, a coarse granite, opposite to the southeast part of New Ulm, succeeded eastward by Algonkian conglomerate and quartzite. Observations of the strike and dip of the Archean rocks exposed in this valley show that the axial lines of their folds run mainly from southwest to northeast.

Central Minnesota has frequent Archean outcrops in Stearns, Benton, and Morrison counties, including the valuable quarries of St. Cloud, Sauk Rapids, and Watab. The greater part of this area is hornblendic granite, and exhibits no laminated or gneissic structure. It has considerable variety of texture as to its coarseness of grain and readiness to be quarried and wrought into any required form. Mostly its color is light-gray, but upon some extensive tracts it has a red tint similar to that of the celebrated granite of Aberdeen, in Scotland. In other portions of this district, micaceous granite, gneiss, and mica-schist are the common rocks, sometimes associated with hornblendic granite. Their strike is usually to the northeast or east-northeast. At Little Falls and Pike Rapids, on the Mississippi, and for several miles to the south, west, and north, as also in northern Todd County, and along the falls of the St. Louis above Fond du Lac, and thence northeastward, is a group of rocks quite different from the foregoing, its range of variation being from highly cleavable clay-slate, and from mica-schist, inclosing many crystals of staurolite and sometimes garnet and iron pyrites, to very compact, tough, and massive diorite. Comparing these rocks with the divisions of the Archean recognized in Canada and elsewhere, the granites and gneisses appear to represent the Laurentian, while the slate, staurolitic schist, and diorite are probably Keewatin.

VICINITY OF THE LAKE OF THE WOODS, RAINY LAKE, AND NORTHWARD.

Belts of granite, gneiss, schists, quartzites, and slates, belonging to the Archean group, alternate with one another, trending to the east or northeast, along the international boundary from the Lake of the Woods to Lake Superior. In the region about the Lake of the Woods they have been described very fully by Dr. A. C. Lawson.[1] The group is there divisible into two systems, the older being the Laurentian granitoid gneisses, and the newer a series of schists, quartzites, and slates, named by Lawson the Keewatin series. In later publications by Dr. Lawson on the geology of the Rainy Lake region,[2] his descriptions show that subsequent to the deposition of a measured thickness of 2 miles of mica-schists and granulitic gneisses, named by him the Coutchiching series, well developed about Rainy Lake, and of the Keewatin series north of Rainy Lake and about the Lake of the Woods, the whole Archean group in this district, comprising a vast thickness of sedimentary and volcanic rocks, and perhaps below these including a part of the first-formed crust of the globe, was subjected to metamorphism from the heat of the earth's interior, whereby the lowest beds observed, to which the name Laurentian is restricted by Lawson, were so fused that portions of them were extravasated through the overlying Coutchiching and Keewatin beds. Such division remains yet to be worked out for nearly all of the Archean area east and north of Lake Winnipeg, but is reported and mapped by Dr. Robert Bell in the country bordering the Hayes and Nelson rivers.

BOUNDARY OF THE ARCHEAN TOWARD THE WEST.

Though the western boundary of the Archean area in Minnesota is mainly covered by drift and by remnants of Cretaceous beds beneath the drift, it is somewhat definitely known for a distance of 160 miles from New Ulm west, northwest, and north, to the south end of Lake Agassiz. Crossing the Minnesota River from the north at New Ulm, it runs westerly about 40 miles, and thence northwesterly across Redwood, Yellow Medicine, and

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. I, 1885, Part CC.

[2] Am. Jour. Sci. (3), Vol. XXXIII, pp. 473–480, June, 1887. Geol. and Nat. Hist. Survey of Canada, Annual Report, Vol. III, for 1887–88, Part F.

Lac qui Parle counties almost parallel with the Minnesota River, but gradually approaching nearer to it and curving north to the mouth of Big Stone Lake. Thence, beneath a veneer of the Cretaceous shales and overlying glacial drift, it passes north-northeasterly to the west part of Grant County, where a well at Herman, 189 feet deep, encountered Archean rocks at a depth of 132 feet. This well first went through 124 feet of till, and then through 7 or 8 feet of fine-grained, buff magnesian limestone. The remaining 57 feet were quartzose granite, with red feldspar, white micaceous quartzite, and mica-schist of several varieties.[1]

Farther to the north, through Minnesota, this boundary is more conjectural because of the almost entire absence of exposures of the bed-rocks. Entering the area of Lake Agassiz east of Red Lake, it turns to the northwest and traverses a region wholly drift-covered, passing not far west of the Lake of the Woods.

North of the international boundary this limit of the Archean area extends a little west of north to the south end of Lake Winnipeg, a few miles east of the mouth of the Red River, and thence, continuing in the same direction, it follows the east shore of Lake Winnipeg along its whole extent to the mouth of the lake. The farther course of this line, according to the observations of Sir John Richardson and later explorations by Dr. Bell and others, of the Geological Survey of Canada, is west-northwest from the mouth of Lake Winnipeg and the west side of Great Playgreen Lake to the south side of Beaver Lake and Lac la Rouge, a distance of 275 miles, and thence it curves gradually to the northwest, crossing the Churchill at the north extremity of Isle à la Crosse Lake.

LOWER SILURIAN FORMATIONS.

In journeying from south to north along the Red River Valley, the first rock exposures found are Lower Silurian strata, chiefly magnesian limestones, which outcrop in Manitoba at numerous localities 12 to 20 miles north-northeast of Winnipeg, and similar outcrops, probably in part of Upper Silurian age, which rise above the general surface of drift 5 to 20 miles northwesterly from Winnipeg and at about the same distances west of

[1] Geol. and Nat. Hist. Survey of Minnesota, Sixth Annual Report, for 1877, p. 29; Final Report, Vol. II, 1888, p. 503.

the river. Farther north Lower Silurian rocks are exposed on many of the islands of Lake Winnipeg and along its western shore, but no exposures of the underlying Cambrian beds, which are penetrated by the artesian well at Grafton, N. Dak., have been found in this region. Against the western border of the folded and eroded Archean rocks the Lower Silurian formations repose with nearly horizontal stratification. Their general dip, varying from a few feet to 10 feet or more per mile, is westward, at right angles with the axis of Lake Winnipeg and the line of junction of the Archean and Paleozoic rocks.

Descriptions of the outcrops of Silurian and Devonian strata in Manitoba will prepare us to consider afterwards the sections of artesian wells farther south, which give evidence that Silurian formations immediately underlie the drift upon a large portion of the Red River Valley, on both sides of the international boundary and of the river, where no rock exposures exist.

Outcrops on Lake Winnipeg.—Near Grindstone Point, on the west side of Lake Winnipeg, 60 miles north from the south end of the lake, Hind observed a section of 18 feet of level limestone overlying 20 feet of sandstone, and refers it, upon the evidence of its fossils, to the Chazy epoch.[1] Beds of limestone, shale, and sandstone are also described by Hind on Deer Island, about 8 miles south of Grindstone Point, being apparently the same strata as at that locality; and Panton reports an extensive outcrop of limestone on the west part of Big Island, a few miles east from Deer Island, and other exposures of the same on Punk Island, 3 or 4 miles to the north. Black Bear Island, a few miles northwest from the Narrows at Dog Head, and Berens or Swampy Island, about 40 miles farther north, also contain low outcrops of limestone, which Panton, who refers them to the same formation with the foregoing, found sparingly fossiliferous on the former but richly so on the latter of these islands.[2]

[1] Report of the Assiniboine and Saskatchewan Exploring Expedition, 1859, p. 86. These beds seem equivalent with the well-defined limestone stratum, about 30 feet thick, richly fossiliferous, which has been commonly called the Trenton limestone in southeastern Minnesota, but which is recently referred by Mr. E. O. Ulrich to the Chazy or perhaps the Black River formation (Geol. and Nat. Hist. Survey of Minn., Fourteenth Annual Report, for 1885, p. 57).

[2] "Notes on the geology of some islands in Lake Winnipeg," by J. Hoyes Panton. Transactions of the Historical and Scientific Society of Manitoba, January 28, 1886.

The basal sandstone of these sections is the lowest formation exposed in this basin above the Archean rocks. It is regarded by Mr. J. B. Tyrrell, of the Canadian Geological Survey, who has recently examined the lake region of Manitoba, as of the same age with the Chazy limestone of New York and the St. Peter sandstone of the Upper Mississippi. He reports its thickness to be about 100 feet, consisting of "white quartzose sandstone, with generally well-rounded grains, running down, at the bottom, into a quartzose conglomerate."[1]

The overlying limestone, called the Trenton formation by Whiteaves and Tyrrell, appears to represent both the Trenton and Galena formations of the Mississippi Valley. It is described by Tyrrell as "consisting at the bottom of a mottled buff and gray dolomitic limestone, found at Big and Swampy islands, etc., and probably also at East Selkirk, above which are other horizontal and evenly bedded limestones and dolomites, amounting in all to a few hundred feet, and all more or less rich in fossils."[2]

Next in ascending order, these authors identify the Hudson River formation, the highest member of the Lower Silurian system, "represented by less than 100 feet of fossiliferous shales and dolomites," at Stony Mountain, at Clarks Point and Harbor, on the west shore of Lake Winnipeg, and, 10 miles south of the last-named locality, on the Little Saskatchewan River from 1 to 3 miles above its mouth.

East Selkirk.—Dolomitic limestone, having a light-buff or cream color, delicately and very irregularly streaked and mottled with light yellowish brown, is quarried in three localities near East Selkirk, on the Red River, about 20 miles north-northeast of Winnipeg. It has been much disturbed by glacial agencies, and most of the quarrying is of large detached blocks, which have been removed slightly from their original position and are embedded in the drift. In one of the excavations a thickness of 10 or 12 feet of the stone is seen in place, having a horizontal stratification, at an elevation approximately 730 to 740 feet above the sea. It contains abun-

[1] "Three deep wells in Manitoba." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, p. 91. Summary Report of the Geological Survey of Canada for 1891, p. 18.

[2] J. B. Tyrrell, as before cited. J. F. Whiteaves, "The Orthoceratidæ of the Trenton limestone of the Winnipeg Basin." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, pp. 77–90.

dant fossils, from which Mr. Whiteaves decides its age to be that of the "Galena limestones of the west, equivalent to the Utica shales."[1]

Lower Fort Garry.—About 5 miles southwest from these quarries, similar limestone is exposed on the west bank of the Red River, at Lower Fort Garry, commonly called the "Stone fort," and along a distance of a half mile to the south. It rises 15 to 20 feet above the river, its top being about 730 feet above the sea. This also contains many fossils, among which are several species, according to Panton, that are not found at East Selkirk, but occur at Stony Mountain. The same formation has another low exposure on the Red River, about 4 miles farther south. From the former of these outcrops, close to the fort, Owen collected fossils which he pronounced identical with those of the Upper Magnesian or Galena limestone of Wisconsin and Iowa.[2]

Stony Mountain.—Twelve miles north-northwest of Winnipeg, and an equal distance west of Lower Fort Garry, is the hill called Stony Mountain, well described by Panton as "like an island of limestone raised above the surface of the surrounding prairie some 60 feet. * * * It is several miles in circumference and resembles in outline the shape of a horseshoe. The west and north sides are quite steep, and along the escarpments the exposed edges of the strata are easily observed, while the east gradually slopes to the prairie level." The highest beds at the quarries on the west side of Stony Mountain are hard, brownish-gray, dolomitic limestone, about 40 feet thick (from 825 to 785 feet, approximately, above the sea), showing only few and obscure fossils, chiefly corals; next is a reddish-gray limestone, with clayey partings, about 10 feet, very fossiliferous, containing many brachiopod shells; and beneath these beds a well at the penitentiary penetrated 60 feet of partially cherty shales, varying in color from yellow to red.

Little Stony Mountain.—Eight miles south of Stony Mountain and 5 miles west-northwest of Winnipeg, an outcrop of limestone, known as Little Stony Mountain, has been quarried for lime-burning. The surface here rises 30 or 40 feet in a half mile, from east to west, to the limekiln and

[1] Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, by A. R. C. Selwyn and G. M. Dawson, 1884, p. 37.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota, 1852, p. 181.

quarries, which are about 800 feet above the sea, and thence it holds nearly this height westward. The limestone, shown to a depth of about 10 feet, is apparently the same as that forming the upper part of Stony Mountain. It lies in beds mostly 1 to 2 feet thick, horizontal, or in part dipping 1 to 2 degrees to the south-southwest.

Stonewall.—At Stonewall, 5 miles northwest of Stony Mountain, a hard and cherty limestone has been extensively quarried, exposing a vertical section of 17 feet. The upper layers of this rock to a thickness of 7 or 8 feet are white and fossiliferous, but it gradually changes below to a red stratum which has no fossils.

From his study of the fossils collected in these outcrops on the Red River and westward, Mr. Panton concludes that their ascending stratigraphic order is the same as their geographic order from east to west, and writes of the series as follows:

> The Selkirk rock has a most comprehensive group of fossils, there being representatives of several beds, but taking them as a whole the Trenton fossils are best represented. The rocks at Lower Fort Garry seem to indicate a transition bed between those of East Selkirk and the lower layer at Stony Mountain. They contain forms common to both. The fossils of the lower layers at Stony Mountain bear a marked resemblance to those found in the Hudson River group elsewhere, while the higher dolomitic beds and those of Stonewall probably border on the Niagara formation.[1]

UPPER SILURIAN AND DEVONIAN FORMATIONS.

West of these Lower Silurian strata, rocks of Devonian age, mostly pale-gray or buff magnesian limestones, occur on Lakes Manitoba and Winnipegosis, as reported in 1884 by Dr. G. M. Dawson; "and it is probable," he wrote, "that the intervening formations will be found to be extensively developed in the Lake Winnipeg region as it is more fully examined."[2]

Subsequent exploration of this region by Mr. J. B. Tyrrell has resulted in the discovery of Upper Silurian strata, containing fossils characteristic

[1] "Gleanings from outcrops of Silurian strata in the Red River Valley." Transactions of the Historical and Scientific Society of Manitoba, November 27, 1884.

[2] Descriptive Sketch of the Physical Geography and Geology of Canada, p. 37.

of the Niagara formation, on the lower part of the Saskatchewan River and on the east side of Lakes Manitoba and Winnipegosis. In the gorge of the Grand Rapids of the Saskatchewan this formation, according to Tyrrell, "consists in its lower portion of about 60 feet of buff, yellow, and white limestone, brecciated at the bottom and ripple-marked toward the top. Some bands are highly fossiliferous. * * * The upper portion of the formation consists of a considerable thickness of a compact or porous dolomite, often containing many impressions of salt crystals. * * * The highest beds at Stonewall may belong to this terrane."[1]

Overlying the typical Niagara dolomites, Mr. Tyrrell finds, near the northeastern angle of Lake Manitoba, "a few feet of thick-bedded stromatoporoid magnesian limestone holding *Pycnostylus Guelphensis*," which he thinks to be probably referable to the Guelph formation, next above the Niagara in the Upper Silurian series.

The succeeding strata of this district, in ascending order, shown to be soft shales in the sections of wells at Rosenfeld and Morden, have not been found in outcrops. These beds doubtless represent higher formations of Upper Silurian age and the base of the Devonian system, which latter seems to be identified by fossils of the Morden section.

Devonian strata are reported by Tyrrell on the western shores and islands of Lake Manitoba and Lake Winnipegosis, being especially well exhibited in the islands of Dawson Bay and of Swan Lake, which lies a few miles south of this bay. Above an exposure of a few feet of red shales, the Devonian series in these outcrops comprises 200 feet or more of fossiliferous magnesian limestone, an overlying thickness of 50 to 70 feet of calcareous shales, whose horizon is marked by many brine springs, and higher beds of richly fossiliferous limestone.[2]

All the Paleozoic formations in the lake region of Manitoba, from the St. Peter sandstone to the highest Devonian beds exposed, are stated by Mr. Tyrrell to be "practically conformable and almost undisturbed through-

[1] "Three Deep Wells in Manitoba." Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, p. 91.

[2] J. B. Tyrrell, paper before cited; also, Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, Vol. IV, for 1888–89, pp. 21, 22A. J. F. Whiteaves, "Descriptions of some new or previously unrecorded species of fossils from the Devonian rocks of Manitoba," Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, pp. 93–110, with seven plates.

out." At Point Wilkins, on the west side of Dawson Bay, the Dakota sandstone, forming the base of the Cretaceous series which underlies the drift farther west, was seen lying on the eroded surface of the horizontally stratified Devonian limestones.

Along the Saskatchewan, Silurian and Devonian strata, mainly limestones, reach from Lake Winnipeg to Fort à la Corne, about 12 miles below the junction of the south and north branches of this river. Thence to the northwest and north, a belt of these rocks, in large part almost horizontally bedded, skirts the west side of the Archean area to the Arctic Sea.

SECTIONS OF ARTESIAN WELLS IN PALEOZOIC STRATA.

Four deep borings for artesian water reveal the order and thickness of the several members of the Paleozoic group forming the floor of the Red River Valley beneath the drift in the vicinity of the international boundary. These wells, in their order from east to west, are situated at Humboldt in Minnesota, Grafton in North Dakota, and Rosenfeld and Morden in Manitoba. Notes of their sections are presented in the following pages, and their stratigraphic relationship is shown in Pl. XV.

The well at Morden penetrates only to the base of the Devonian or top of the Upper Silurian. The Rosenfeld well, entering the bed-rocks at a horizon near that where the Morden well left off, gives apparently a complete section of the Upper and Lower Silurian series, passing at its bottom through the Lower Magnesian formation, which is the base of the latter, lying next below the St. Peter sandstone. Another section of the Lower Silurian formations, from the Galena and Trenton to the Lower Magnesian, is supplied by the well at Humboldt; and the Grafton section, besides duplicating that of Humboldt, passes nearly 300 feet beyond in probably Upper Cambrian strata, referable to the Jordan, St. Lawrence, and Dresbach formations of the St. Croix series.

WELL AT HUMBOLDT, MINN.

Humboldt is a station of the Great Northern Railway, about 7 miles southeast of St. Vincent, at the farm of Mr. D. H. Valentine, on which this well is situated. It is on the flat plain of the Red River Valley, 6 miles

east of the river and 5 miles south of the international boundary. The elevation of the surface is 792 feet above the sea, being a few feet above the highest flood stage of the Red River. On account of the saltness of its water, an analysis of which is given in Chapter X, the well is not used.

Prof. N. H. Winchell has reported this section,[1] shown by samples from the boring, a summary of which is as follows:

Section of an artesian well, Humboldt, Minn.

	Feet.
Soil and very fine sandy clay, stratified	16
Moister and darker, more impervious clay, apparently a downward continuation of the foregoing, but probably including pebbles and bowlders, at least sparingly, in its lower portion, being there bowlder-clay or till	124
Pebbly blue till, containing salt water in small quantity at 165 feet below the surface	30
Drift gravel and sand, mainly a gray sand, but containing pebbles up to an inch in diameter, mostly of limestone; supplying an abundant artesian flow of salt water	10
Cream-colored magnesian limestone, of grain and texture like the Lower Magnesian in southeastern Minnesota [and equally like the Galena or Upper Magnesian and Trenton formation in Manitoba], showing near its base some intermixture of grains of white quartz	295
Sandstone, composed of rounded quartz grains, reddish in its upper part for 25 feet, white in its central part, from both of which the artesian flow of salt water increased, and faintly reddish in its lowest 10 feet	71
Shales, varying in color from red and brown to gray and green, with occasional siliceous layers that vary from white sand to slightly calcareous, grayish quartzite	92
Gneiss or granite, composed of opaque gray quartz, flesh-colored orthoclase, also a white feldspar and black mica, "evidently one of the Laurentian granites as seen at the Lake of the Woods," into which the boring extended	6
Total	644

Drift deposits here reach a depth of 180 feet, below which are 458 feet of strata referable to the Trenton, Chazy, and Calciferous series of the Lower Silurian system.

[1] Geol. and Nat. Hist. Survey of Minnesota, Thirteenth Annual Report, for 1884, pp. 41–46.

Next beneath the drift is a thick formation of magnesian limestone, shown by comparison with the other wells to be the Galena and Trenton strata, classed together as one formation under the second of these names by Whiteaves and Tyrrell, which outcrops at a distance of 75 to 85 miles northward, in the vicinity of Lower Fort Garry and East Selkirk, Manitoba. Its top and bottom at Humboldt, however, are respectively 612 and 317 feet above the sea, the entire formation here being thus beneath the level of Lake Winnipeg. In southeastern Minnesota, southwestern Wisconsin, and adjoining portions of Iowa and Illinois, the Galena and underlying Trenton limestones together range from 200 to 300 feet or more in thickness.

The sandstone next below, having a thickness of 71 feet, is evidently the equivalent of the St. Peter sandstone, referable to the Chazy epoch, which in southeastern Minnesota underlies the Trenton limestone, and ranges in thickness there from about 75 feet to 164 feet. Its continuation in Wisconsin, as described by Chamberlin and Irving, averages probably between 80 and 100 feet thick, varying from a maximum of 212 feet down to a fraction of 1 foot. In this and adjoining States, according to Irving, it is continuous "over a region whose diameters are 500 and 400 miles."[1]

Beneath this the Humboldt well penetrated 92 feet of shales, partly arenaceous and calcareous, which correspond to the Lower Magnesian or Shakopee limestone of southeastern Minnesota, ranging from 96 feet in thickness at Shakopee to 200 feet in Houston County, while in Wisconsin it is from 65 to 250 feet thick. The reports of the geological surveys of these States regard this formation as of Upper Cambrian age, but Walcott, in his more recent review of the Cambrian,[2] assigns the Lower Magnesian limestone wholly or mainly to the base of the Lower Silurian system. Its eastern equivalent is the Calciferous sandrock of New York.

The entire Cambrian and Algonkian systems are wanting in this section, and the Lower Silurian strata rest directly on the Archean crystalline rocks.

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[1] Geology of Wisconsin, Vol. I, pp. 145–150; Vol. II, p. 555.
[2] U. S. Geol. Survey, Bulletin No. 81, 1891, p. 363.

WELL AT GRAFTON, N. DAK.

The city of Grafton is also on the Red River Valley plain, being situated 12 miles west of the river and 40 miles south of the international boundary, at an elevation of 825 feet above the sea. Its distance from Humboldt is about 38 miles to the south-southwest. The following record of the boring here was made by the engineer in charge during the progress of the work, and was supplied to me by the mayor, Mr. J. Tombs, at the time of my visit to Grafton in the survey of the shore-lines of Lake Agassiz. It has been published by the Dakota commissioner of immigration.[1]

Section of an artesian well, Grafton, N. Dak.

	Feet.
Black loam	3
White clay	25
Blue clay	250
Hardpan	20
Limestone	137
Quicksand	20
White, coarse sand	45
Slate	3
Sandstone, yielding a copious flow of brackish water	25
Red shale	60
Blue shale	16
Pink shale	11
Gray gravel	49
Red shale	46
Soapstone [clayey shale]	188
Sandstone, yielding a small flow of very salt water	5
Granite	12
Total	915

Glacial drift, doubtless mostly till, with a thin covering of lacustrine and alluvial clay, reaches to the depth of 298 feet.

The limestone next encountered, with a thickness of 137 feet, evidently is the lower portion of the thick formation of limestone of Galena and

[1] Resources of Dakota, 1887, p. 188.

Trenton age, found next beneath the drift in the Humboldt well, its upper part here having been lost by erosion.

The St. Peter sandstone occupies a thickness of 93 feet.

Red, blue, and pink shales, representing the Lower Magnesian formation, ensue, with a thickness of 87 feet.

The next stratum, 49 feet thick, is probably the equivalent of the Jordan sandstone, the highest division in the St. Croix series of the Upper Cambrian. Its thickness in southeastern Minnesota ranges from 40 to 116 feet, and in Wisconsin, where it is known as the Madison sandstone, it is from 30 to 60 feet thick.

The succeeding shales, having a thickness of 234 feet, appear to represent the St. Lawrence formation, the second in the St. Croix series, which in southeastern Minnesota varies from 128 to 213 feet in thickness.

Beneath the shales, the thin bed of water-bearing sandstone, lying on the granite, may be a trace of the Dresbach sandstone, a third division of the St. Croix, which has a thickness of 50 to 80 feet or more in southeastern Minnesota. The brine rising from this bed was analyzed by Prof. Henry Montgomery, of the University of North Dakota, and was found to be more saline than sea water.

Samples of the borings in the lowest 12 feet were submitted to Prof. N. S. Shaler, who pronounced them to be granite or gneiss, being the Archean bed of the ocean in which the overlying Paleozoic strata were deposited.

The water used from this well is taken from the St. Peter sandstone, the lower part of the bore having been filled. The diameter of the pipe is 6 inches, and the flow, according to three measurements in 1886 and 1887, during the first year after the completion of the well, was 800 gallons per minute.

WELL AT ROSENFELD, MANITOBA.

Rosenfeld is situated 14 miles north of the international boundary and 11 miles west of the Red River, being 30 miles northwest of Humboldt, and about 54 miles distant, in a direction slightly west of north, from Grafton. Like Humboldt and Grafton, it is on the flat plain of the Red

River Valley, and the elevation is the same as at Humboldt, within 1 foot, the railway at Rosenfeld, 3 feet above the surface at the well, being 796 feet above the sea. A summary of the section of this well, according to records and samples of the boring supplied by Mr. W. E. Swan, who drilled it,[1] is as follows:

Section of an artesian well, Rosenfeld, Manitoba.

	Feet.
Black soil	4
Fine silt or clay, alluvial and lacustrine in its upper portion, but below probably including a considerable thickness of bowlder-clay or till	111
Sand and gravel	10
Bowlder-clay ("hardpan")	12
Bowlders	6
Gray shale	62
Cream-colored or buff limestone	15
Red shale	5
Gray shale	10
Cream-colored limestone, beneath which was encountered a small artesian flow of salt water	30
Fine gray sandstone or sandy shale	40
Chalky limestone, varying in color from white to pale greenish and reddish gray.	30
Red shale, containing much subangular quartz, in grains which are very irregular in size, some being quite coarse	160
Cream-colored magnesian limestone, beneath which came an additional artesian flow of salt water	305
Red shale, with much quartz in subangular grains	75
Soft sandstone, consisting of rounded and polished quartz grains, white, but reddish in the drillings from its upper portion, apparently because of admixture of the overlying shale; yielding a large artesian flow of salt water, the supply of which was increased to four times its previous quantity	50
Dark-red shale, with greenish-gray interlaminations	50
Reddish and greenish shale	25

[1] Published by Prof. N. H. Winchell in the Fourteenth Annual Report of the Geol. and Nat. Hist. Survey of Minnesota, for 1885, p. 15; and by Dr. G. M. Dawson, "On certain borings in Manitoba and the Northwest Territory," Trans. Roy. Soc. Canada, Vol. IV, sec. 4, 1886, pp. 85–91. Dr. Dawson supplements the brief record kept by Mr. Swan with many descriptive notes from his examination of the samples; and his identification of the lower formations, which this well has in common with the Humboldt and Grafton wells, is here followed. The strata above the Galena limestone were referred by Dawson wholly to the Hudson River epoch; but comparison with the Morden well indicates that they probably include not only Hudson River beds, but also the Niagara and other Upper Silurian formations, nearly or quite to the base of the Devonian.

	Feet.
Bluish and gray shale	20
Red shale or clay, inclosing much quartz sand	15
Granite or gneiss, chiefly composed of quartz and red feldspar in rather small crystals	2
Total	1,037

Alluvial and lacustrine silts and drift deposits reach a depth of 143 feet, the top of the bed-rock being 60 feet below the level of Lake Winnipeg. Examining the succession of strata penetrated below, we confidently recognize the thick limestone formation which extends between the depths of 495 and 800 feet as the same that is found with nearly as great thickness in the Humboldt well. It is referable, as Dr. Dawson concludes, to the Galena limestone, passing below into the Trenton. In the distance of 30 miles from Humboldt this limestone sinks somewhat more than 300 feet, averaging between 10 and 11 feet per mile. Comparison with the Grafton well, in which the base of this formation lies 73 feet higher than at Humboldt, indicates an approximately west-northwest direction for the maximum dip of the strata here, so that probably they sink at about the same rate, nearly 11 feet per mile, in the distance of 24 miles from Rosenfeld west to Morden, as from Humboldt northwest to Rosenfeld. Such inclination from the top of the section under the drift at Rosenfeld would coincide very nearly (as shown in Pl. XV) with the bottom of the Morden well, from which Mr. Tyrrell reports fossils belonging to the lower part, probably the base, of the Devonian series.

From these considerations, it appears that the 192 feet of shales, limestones, and sandstone shown by this section next below the drift must represent the whole Upper Silurian series of this district, and that the lower 100 feet of this thickness are probably the Guelph and Niagara formations. The lowest of these limestones, 30 feet thick, seems to be the equivalent of the limestone of Stonewall and the top of Stony Mountain.

The Lower Silurian series includes the next 160 feet of red shale, belonging to the Hudson River formation; the 305 feet of Galena and Trenton limestone; the underlying red shale and St. Peter sandstone, together 125 feet thick; and, finally, 110 feet of shales, occupying the place of the Lower Magnesian limestone.

WELL AT MORDEN, MANITOBA.

Morden is due west of Rosenfeld at a distance of 24 miles, lying on the border of the broad plain which extends from the Red River to the Pembina Mountain. Its elevation is 978 feet above the sea. A well, reported by Tyrrell, was drilled here to the depth of 600 feet, during the winter and spring of 1889–90, with the hope of obtaining artesian water. Its section was alluvial sand and fine gravel, 15 feet; till, 16 feet; gray Cretaceous shales, referred to the base of the Fort Pierre formation and the next lower Niobrara and Fort Benton formations, 289 feet; the white Dakota sandstone, 92 feet; and red and gray shales, with porous limestone, representing, as shown by their fossils, probably the base of the Devonian system, 188 feet. The westward dip of the strata in the Humboldt and Rosenfeld wells carries them beneath the bottom of the Morden well. No artesian flow was obtained at Morden, but from the top of the Dakota sandstone strongly saline water rose to within 6 feet of the surface.

CRETACEOUS FORMATIONS.

Cretaceous beds lie on the west border of the Archean rocks in Minnesota; and farther north, along the west side of the lower part of the Red River Valley and of Lakes Manitoba and Winnipegosis, they rest upon the Lower and Upper Silurian and Devonian strata that form the floor of this broad, flat valley, beneath its glacial, lacustrine, and fluvial deposits. Thence northwestward to the Mackenzie and the ocean Cretaceous beds border and overlie the west part of the Silurian and Devonian belt. West of Lake Agassiz the Cretaceous area has a width of 600 to 700 miles, including the entire region of the elevated plains, and terminating at the east base of the Rocky Mountains.

Marine series of the Upper Missouri.—In the region of the Upper Missouri River, formations belonging to the middle and later portions of the Cretaceous period are well developed. Meek and Hayden there identified five members of this system, in descending order as follows:[1] The Fox Hills formation, gray, ferruginous, and yellowish sandstone, and arena-

[1] Report of the U. S. Geological Survey of the Territories, 1870, p. 87.

ceous shales, 500 feet; the Fort Pierre formation, dark-gray and bluish shales and plastic clays, 700 feet; the Niobrara formation, lead-gray calcareous marl, passing down into light-yellowish and whitish limestone, 200 feet; the Fort Benton formation, dark-gray laminated shales and clays, sometimes alternating near the upper part with seams and layers of soft gray and light-colored limestone, 800 feet; and the Dakota formation, yellowish, reddish, and occasionally white sandstone, with, at places, alternations of various-colored shales and beds and seams of impure lignite, 400 feet. Leaves of dicotyledonous trees, including many genera still existing, are found in the Dakota formation; also a few species of fresh-water or brackish-water and marine shells. The formations here enumerated above this are marine deposits, as shown by plentiful fossils throughout the greater part of the series.

More recent classifications by King, White, and Eldridge unite the two members of this series next above the Dakota, naming them together the Colorado formation; and in like manner the succeeding two still higher are united and named the Montana formation.[1] For the purpose of the present chapter, however, it will be more convenient to use the older designations.

In the South Saskatchewan basin.—North of the international boundary, the development of these portions of the Cretaceous system in the region of the Bow and Belly rivers, which unite to form the South Saskatchewan, is reported by Dr. George M. Dawson as follows: The Fox Hills sandstone, in some parts of the district well defined as a massive yellowish sandstone, but inconstant, 80 feet; the Fort Pierre formation, neutral-gray or brownish to nearly black shales, marine, 750 feet; the Belly River formation, an extensive fresh-water and brackish-water series, consisting of sandy argillites and sandstones, the upper portion characteristically pale in tint, the lower generally darker and yellowish or brownish, probably of the same age with the Niobrara formation, 910 feet; and lower dark shales, observed on the upper part of Milk River, regarded as representing the Fort Benton member of the Upper Missouri section, 800 feet. The lowest or Dakota formation is not recognized in that district. Valuable beds of lignite are

[1] C. A. White, "Correlation Papers—Cretaceous," U. S. Geological Survey, Bulletin No. 82.

found in the Belly River series and at the base and top of the Fort Pierre formation. "The Belly River series," Dawson writes, "appears to correspond precisely to that occupying a similar stratigraphical position on the Peace River, and there designated the Dunvegan series. These indicate the existence of a prolonged interval in the western Cretaceous area during which the sea was more or less excluded from the region, and its place occupied for long periods by lagoons or fresh-water lakes."[1]

Along the Manitoba escarpment.—The Cretaceous series forming the Manitoba escarpment and underlying its base has been recently studied and described by Mr. J. B. Tyrrell, of the Canadian Geological Survey.[2] He divides the Fort Pierre formation into two parts, naming the upper part, about 500 feet in thickness, the Odanah series. This division "consists almost entirely of greenish-gray clay shale, which, when wet and in place, is soft enough to be easily cut with a knife, but on drying becomes quite hard and brittle. It occupies all the top of the Pembina and Riding mountains, but farther north no exposures of this series were seen, the country throughout being very thickly covered with drift. No fossils of any kind were found in this terrane."

The lower part of the Fort Pierre shales, named the Millwood series, also mainly about 500 feet thick, and attaining a maximum of 664 feet in the well bored at Deloraine, "consists of soft, dark-gray clay shales, with nodules of ironstone in which many species of typical Pierre fossils have been found. The terrane is well exposed at Millwood, 18 miles above Fort Ellice, on the Assiniboine River, and it may also be seen in the gorges cut by the Ochre and Wilson rivers on the northeastern face of the Riding Mountain, in the gorge of North Pine River in the Duck Mountain, and * * * on the eastern face of Porcupine Mountain."

The Niobrara formation, as recognized by Tyrrell in borings on the Vermillion River at the northeastern base of the Riding Mountain escarp-

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1882-83-84; and Descriptive Sketch of the Physical Geography and Geology of Canada, 1884.

Sir William Dawson, Whiteaves, and Cope find the fossils of the Belly River series "identical with those of the Laramie." Am. Naturalist, Vol. XXI, p. 171, February, 1887.

[2] "The Cretaceous of Manitoba," Am. Jour. Sci. (3), Vol. XL, pp. 227-232, September, 1890; and "Foraminifera and Radiolaria from the Cretaceous of Manitoba," Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, 1890, pp. 111-115.

ment, and at Morden and Deloraine,[1] varies in thickness from 128 to 545 feet. It comprises gray, principally calcareous shales, with "a band of light-gray chalk, or mottled-gray chalk marl, about 200 feet in thickness, outcropping along the foot of the Porcupine, Duck, and Riding mountains, but lying below what is generally known as the Pembina escarpment on the eastern face of the Pembina Mountain. * * * The Niobrara is generally harder and more resistant than the terranes either above or below it, and it often forms little abrupt cliffs in the midst of an otherwise gently sloping country. It is, however, by the constant presence of great numbers of foraminifera that this terrane can be identified with the greatest ease either in natural exposures or in the mud or small fragments of rock taken from the wells bored with a percussion drill. These drillings, as a rule, appear very uninviting to the geologist, but in the present case, when they are carefully washed free from the impalpable clay that forms a large part of their bulk, and examined under the microscope, they are found to determine the Niobrara horizon with almost as much accuracy as if good hand specimens of the rock had been obtained."[2]

In these borings the Fort Benton formation is represented by a stratum of gray shales, from 105 to 178 feet thick, underlain by the Dakota sandstone, which had a thickness of only 19 feet on the Vermillion River, and, with interbedded shales, was found to be 92 feet thick at Morden, resting in both these wells on Devonian strata. Elsewhere in this district, outcrops of the Dakota sandstone, and wells penetrating it, show that its thickness ranges from 50 to 150 feet.

The brackish- and fresh-water Laramie formation.—The marine Cretaceous strata of the Upper Missouri country are overlain by the highest member of this system, the Laramie formation, which was deposited in brackish and fresh water. This series covers a broad belt in North Dakota and Montana, and stretches southward to Mexico and northwestward into Assiniboia and Alberta. It is also well developed, but with interruptions, along the Mackenzie to the Arctic Sea. The paleontologic characters of the Laramie beds caused it to be long held in dispute whether they

[1] "Three Deep Wells in Manitoba," Trans. Roy. Soc. Canada, Vol. IX, sec. 4, 1891, pp. 91–104.
[2] Trans. Roy. Soc. Canada, Vol. VIII, sec. 4, 1890, p. 113.

should be classed with the Cretaceous or the Eocene, since they contain reptilian fossils of Cretaceous types, mollusks allied partly with the Cretaceous and partly with the Eocene, and a flora resembling that of the Miocene in Europe. From the presence of beds of lignite coal, the name Lignitic was formerly often applied to this formation.

In the Missouri and Saskatchewan region the Laramie series consists mainly of sandy shales and sandstones. The similar strata in the vicinity of the Bow and Belly rivers, referred to the Laramie by Dawson, have a thickness of 5,750 feet, and are wholly fresh-water deposits except near their base. On the Missouri River this series reaches from near Bismarck westward by Fort Union and across the Yellowstone to the Milk and Musselshell rivers. At Sims, on the Northern Pacific Railroad, about 40 miles west of Bismarck, it contains a layer of lignite 8 feet thick, which is extensively mined. Northward the Laramie series occupies the upper portion of the basin of the Souris or Mouse River, and forms the Missouri Coteau to the Canadian Pacific Railway and the South Saskatchewan, and probably will be found continuous northwest along this coteau to the North Saskatchewan. Near the base of Turtle Mountain, which beneath its thick covering of drift is an extensive outlying area of Laramie strata, also on the Souris, and on the Bow and Red Deer rivers, head streams of the South Saskatchewan, the lower part of this formation bears workable seams of lignite, apparently on nearly the same horizon with the mine at Sims, in the central part of North Dakota.

The western plains a lacustrine and land area since the early part of the Laramie epoch.—Miocene conglomerate, sandstone, and sandy clays, of fluvial and lacustrine deposition, are found lying on the Laramie and other Cretaceous formations in the Hand Hills, northeast of Red Deer River, and in the Cypress Hills, between the South Saskatchewan and Milk rivers. They are remnants of strata that probably once thinly overspread considerable portions of the upper Saskatchewan region. Five hundred miles southeast from the more southern of these localities an extensive area of fresh-water Tertiary deposits, of Miocene and Pliocene age, begins on White River, in the southwestern part of South Dakota, and reaches southward through Nebraska to western Kansas. No marine Tertiary formations

are known in this interior portion of the continent. Since the early stages of the Laramie epoch, the bed of the Cretaceous ocean now forming the great belt of plains that stretches west from the lake district of Manitoba, the Red River Valley, and eastern Nebraska and Kansas, to the Rocky Mountains, has not been submerged beneath the sea.

FORT PIERRE SHALES WEST OF LAKE AGASSIZ.

The ascent upon Cretaceous strata, at the south a massive ridge and at the north a bold escarpment, on the western border of the valley in which Lake Agassiz lay, called in successive portions the Coteau des Prairies, Pembina, Riding, and Duck mountains, and the Porcupine and Pasquia hills, has mostly so thick and continuous a covering of glacial drift that only few exposures of the underlying strata are seen, chiefly where channels have been eroded by streams. Throughout their extent of 800 miles the ridge and escarpment appear to consist mainly of the Fort Pierre formation, presenting a thickness of several hundred feet of dark shales, mostly soft and somewhat sandy. Under the Fort Pierre beds are similar shales belonging to the Niobrara and Fort Benton formations, succeeded below by the Dakota sandstone. The overlying drift varies commonly from 10 or 20 feet to more than 100 feet in depth.

Southwestern Minnesota and the Coteau des Prairies.—Outcrops of the Cretaceous strata on the Coteau des Prairies, and in Minnesota east of this highland, are rare and usually of small extent, both in area and in the vertical thickness exposed; but these beds are also occasionally penetrated by wells near the east base of the coteau, and at the mission school, $1\frac{1}{2}$ miles north-northwest of the Sisseton Agency, on the eastern slope of the coteau and about 1,500 feet above the sea, a well boring passed through the drift and entered soft shale or clay, probably the lower part of the Fort Pierre formation, at the depth of 138 feet. The outcrops mentioned east of the Coteau des Prairies appear to belong mostly to the lower divisions of the Upper Missouri series. They include sandstones of the Dakota formation on the Cottonwood River, from its mouth to a distance of 30 miles west, yielding numerous species of fossil leaves; beds of shale, with thin seams of lignite and lignitic clay, occurring in the bluffs of the Minne-

sota River about 15 and 30 miles northwest of New Ulm, referred by Prof. N. H. Winchell to the Fort Benton formation; similar deposits about 70 miles farther north, on the Sauk River in Stearns County, identified as this formation by Meek; and shales, with layers of concretionary limestone, in the Minnesota Valley, at the mouth of the Cottonwood, close to New Ulm, which Professor Winchell refers provisionally to the Niobrara formation. In the western outcrops on the Cottonwood, lignite-bearing shales and the sandstone containing impressions of leaves occur together, and the same is true of the shales with limestone and the leaf-bearing sandstone at the mouth of this river; so that possibly all these beds on the Cottonwood and Minnesota rivers may belong to one formation, which must then be the Dakota, according to Lesquereux's determinations of its fossil leaves.

There is evidence, however, that the ocean extended east nearly across Minnesota in later stages of the Cretaceous period, for Cretaceous fossils and shale have been found in the glacial drift, apparently not far removed from their original beds, at Lime Springs, Iowa, less than 5 miles south from the south line of Fillmore County, Minn., including sharks' teeth closely like *Otodus appendiculatus* Ag., bones, teeth, and scales of teleost fishes, *Ammonites* (two species), *Ostrea*, *Inoceramus*, etc., regarded by Dr. C. A. White as Upper Cretaceous, "as late as any yet recognized in any part of North America."[1] A hundred and seventy-five miles northwest from this locality a perfect tooth of *Otodus appendiculatus* Ag. has been found on a sand bar near the mouth of Two Rivers, tributary to the Mississippi, in Morrison County, Minn. Other sharks' teeth and fragments, belonging to different species, have also been found in that vicinity and on the south branch of Two Rivers, in Stearns County, at a distance of about 8 miles to the southwest. These indicate that marine Cretaceous beds, probably of the same age with the fossils at Lime Springs, underlie the drift somewhere in central Minnesota; though it is possible that they have been wholly eroded, their fossils being now contained in the drift. At the mouth of Two Rivers, fresh-water shales, probably of similar middle Cretaceous age with the lignite-bearing beds of the Sauk and Minnesota rivers, are exposed to the height of a few feet above the level of the

[1] Proc. A. A. A. S., 1872, Vol. XXII, pp. 187–192.

Mississippi, containing *Margaritana* and *Unio*, with a thin seam of lignite and lignitic clay. All the Cretaceous deposits of western Minnesota, except in the high Coteau des Prairies, now exist only as a somewhat thin and often discontinuous sheet, ranging in thickness up to maxima of probably nowhere more than 100 to 300 or 500 feet, on the Archean, Algonkian, and Silurian rocks. They are doubtless remnants of the base of a considerable thickness of strata, perhaps originally including the entire Cretaceous series of the Northwest, from the Dakota to the Laramie.

A section of the drift and Cretaceous beds forming the eastern footslope of the Coteau des Prairies is reported by Prof. N. H. Winchell from a well at Tracy, about 60 miles west of New Ulm, 619 feet above the Minnesota River at that place, and 1,403 feet above the sea-level. Till extends from the surface to the depth of 120 feet; next is fine gravel, largely of limestone, 5 feet, including also fine sand and soil-like matter, believed by Professor Winchell to be "a remnant of the old soil which accumulated on the Cretaceous rocks during the Tertiary age;" under this is fine blue clay, 20 feet; then a second bed of gravel, 20 feet, containing pebbles of buff limestone and of gray and dark or reddish quartzite, also of gray conglomerate or coarse sandstone, ranging in size from an inch in diameter to sand grains, with much slag and traces of lignite, from which characters, according to Professor Winchell, this bed "can be supposed to have accumulated on the Cretaceous after the withdrawal of the Cretaceous ocean, the slag coming from the combustion of the lignites contained in the strata." From the bottom of this gravel, at the depth of 165 feet, Cretaceous beds of clay, shale, and sandstone reach 525 feet, having a prevailingly dark color for 446 feet, but mostly white for the lower 79 feet. In descending order, they are fine blue clay, 12 feet; fine greenish-blue sandstone, 20 feet; dark-gray shale, 213 feet; again, fine greenish-blue sand, 60 feet; blue clay or shale, 43 feet; quartzitic white sandstone, with concretionary pyrite, 32 feet; fine gray sandstone, 5 feet; again, blue clay or shale, 30 feet; a second layer of quartzitic and pyritous white sandstone, 7 feet; dark, unctuous, fine clay, 24 feet; white kaolinic clay, becoming reddish, then bluish and gritty, 8 feet; white and gray quartz sand, partly cemented by pyrite and mixed in its lower part with kaolinic clay, 18 feet;

white kaolin, clouded with blue clay, and containing some grit, 25 feet; and white quartzitic sandstone, 28 feet, containing kaolinic material in its lower part, "apparently resulting from the decay of grains of feldspar after deposition in the sandstone."[1]

The thickness of 446 feet of principally dark beds, lying between 1,238 and 792 feet above the sea, probably corresponds to the Fort Benton shales and Dakota sandstone, containing lignite and impressions of leaves, on the Cottonwood and Minnesota rivers, where their elevation is approximately 800 to 1,000 feet above the sea. Under these the thickness of 79 feet of mostly white kaolinic clay or shale and sandstone, constituting the base of the Dakota formation here, appears to be the same with the deposits of white and greenish clay, often sandy and gritty, which lie in water-worn hollows of the Cambrian strata along the lower part of the Minnesota River. These earliest Cretaceous sediments were evidently derived from erosion of decomposed surfaces of the adjoining Archean gneiss and granite. Not all of this decayed and kaolinized rock was worn away then nor by the later erosion of the Glacial period; for at many places in the Minnesota Valley, along the distance of nearly 50 miles between Granite Falls and Fort Ridgely, it forms the upper 10 to 20 or 30 feet of the Archean outcrops. At 713 feet above the sea-level the Cretaceous deposits of Tracy rest on reddish granite of Archean age, into which this well was drilled 34 feet, to a total depth of 724 feet.

In the village of Browns Valley, situated between Lakes Traverse and Big Stone, in the channel of which Lake Agassiz outflowed southward, a well has been sunk to the depth of 465 feet, extending from 975 to 510 feet, approximately, above the sea-level. The general surface on each side of this valley or channel is about 1,100 feet above the sea, 125 feet of glacial drift having been eroded above the site of the well. After passing through an undetermined thickness of alluvial and drift deposits, this well penetrates dark-bluish, hard clay or shale to the depth of 360 feet; a black layer of lignitic shale, 2 feet; gravel and sand, alternating with layers of blue clay, 58 feet; quartzitic sandstone, 5 feet, from above and beneath which artesian flows of water are obtained; greenish, micaceous, and kaolinic

[1] Geol. and Nat. Hist. Survey of Minnesota. Fourteenth Annual Report, for 1885, pp. 351–353.

shale or clay, 20 feet; and white and gray sandy shale or sandstone, 20 feet, in which the well stopped, not reaching the Archean rocks.[1] These strata above the source of the artesian water are probably equivalent to the dark beds of the Tracy well, while the lower strata correspond to the white and kaolinic lower beds there.

Comparing the elevations of the top of the kaolinic deposits in these wells, there is seen to be a slight dip of the strata toward the north-northwest, amounting to about 240 feet in the distance of 112 miles from Tracy to Browns Valley. Another comparison is afforded by a well near Sleepy Eye, which is 45 miles east of Tracy and 1,034 feet above the sea, penetrating 182 feet of drift; then 79 feet of white and gray Cretaceous clay, containing one thin stratum of brownish-red clay, together corresponding apparently to the lowest 79 feet of the Cretaceous beds in the Tracy well, and lying, like those beds, on Archean red granite.[2] These observations indicate a slight westward dip, amounting to about 60 feet, in the Cretaceous strata between Sleepy Eye and Tracy. The resultant inclination satisfying both these sets of observations is a dip of about 3 feet per mile to the northwest, being thus directed away from the ridge of Algonkian quartzite, 1,300 to 1,700 feet above the sea, which outcrops in northern Cottonwood County, on the east flank of the Coteau des Prairies, and in Pipestone and Rock counties, on its west side.

Above the strata thus far described, a hard, gray, somewhat calcareous and concretionary sandstone, probably representing the Niobrara formation, is seen in a few low outcrops near Alta Vista, in the northeast corner of Lincoln County, and within 7 miles eastward, having an elevation approximately 1,175 to 1,150 feet above the sea. These outcrops are 30 to 35 miles northwest from Tracy, and occupy nearly the same stratigraphic horizon with the gravel bed, between 145 and 165 feet in depth, in the well at that place. The only organic remains detected in this sandstone are particles of lignite and traces of wood.

Clay or shale, containing fossils characteristic of the Fort Pierre and Fox Hills formations, the upper members of the marine Cretaceous series, has been encountered in numerous instances by wells in the same region,

[1] Geol. and Nat. Hist. Survey of Minnesota, Fourteenth Annual Report, p. 14.
[2] Ibid., p. 15.

within 7 miles north and 20 miles southeast from Alta Vista, along the foot of the steep eastern ascent of the Coteau des Prairies, at elevations from 1,150 to 1,250 feet above the sea. Perhaps some of these wells have reached Cretaceous strata in place; but others evidently have been wholly in the glacial drift, containing disrupted and transported masses of Cretaceous shale with fossils. The frequency of these fossils in the drift indicates that Upper Cretaceous marine strata originally covered much of this district and supplied a large part of the drift, and that they probably underlie the drift in the Coteau des Prairies. The list of fossils thus found includes *Baculites ovatus* Say, *Placenticeras* (*Ammonites*) *placenta* Dekay, both these represented by abundant specimens, chiefly fragments; *Scaphites nicolletii* Morton, *Nucula cancellata* M. & H., and an *Inoceramus* which may be *I. problematicus* Schlot.[1] Twenty-five miles distant to the southwest and west the crest of the Coteau des Prairies attains a height of 1,950 to 2,000 feet above the sea, rising 800 feet above the outcrops and wells here noted. This massive highland, beneath its mantle of drift, which probably varies from 50 to 250 feet in thickness, doubtless consists mainly or wholly of the Fort Pierre and Niobrara clays and shales, dipping very slightly to the west and northwest. Because of the soft character of these beds, they are not exposed in any projecting knob or ridge; and their resemblance in material and color to the bowlder-clay or till, which is derived in large part from them, makes their exposures less liable to be noticed if they are anywhere cut into by ravines.

Along the Sheyenne River.—The Fort Pierre shales have plentiful exposures in the bluffs of the Sheyenne River, from where it flows by the Cretaceous hills west and south of Devils and Stump lakes, covered partly with morainic drift, as described in the next chapter, to the most southern bend of this river, where it enters the area of Lake Agassiz. A sheet of till, varying from 10 to 50 feet or more in thickness, sometimes with overlying beds of gravel and sand, forms the upper part of the Sheyenne bluffs, and their lower portion consists of the dark-gray, easily disintegrating, sandy shales of this formation to heights varying from 50 to 175 feet above the river. There are many excellent sections of both the shales and the

[1] Geol. and Nat. Hist. Survey of Minnesota, Final Report, Vol. I, 1884, p. 600.

drift, where the slope has been so lately undermined that the shale forms continuous cliffs from a few hundred feet to a quarter or half of a mile in length.

Fossils are infrequent, but would doubtless be detected in many places by careful search. On the western slope of a hill, partially bared of drift and consisting of this shale, near the west line of section 33, township 139 north, range 58 west, 8 miles south of Valley City and about 1½ miles west of the Sheyenne, I found *Inoceramus sagensis* Owen, fragments of other lamellibranchs, and *Baculites ovatus* Say. These were on nearly the average level of the surrounding country, at a height of about 175 feet above the river, or 1,350 feet above the sea.

In the vicinity of the southern bend of the Sheyenne are scanty exposures of Cretaceous beds which contain lignite and may belong to the Fort Benton formation. The lowest outcrop, situated just within the highest shore-line of Lake Agassiz, is in the southeast quarter of section 32, township 135, range 54, about 20 rods west of Edward Bowden's house. Here the east or right bank of the Sheyenne shows the following section, in descending order: Soil and gray clay, with slight intermixture of gravel, 2 to 3 feet; very coarse iron-rusty gravel, from 1 inch to 1 foot thick, containing cobbles of limestone, granite, and a partly decayed gneiss, of all sizes up to 6 and 12 inches in diameter; gray till, very compact, 1 to 1½ feet; fine gravel and sand, about 6 feet, containing in some portions very plentiful flakes and fragments of lignite from an eighth of an inch to 2 or 3 inches long; and hard, dark-bluish Cretaceous shale, seen only to the depth of a few feet and hidden below by the talus, containing near its top a layer of lignite about 3 inches thick, at the height of 25 or 30 feet above the river, and approximately 1,060 feet above the sea. Springs issue from the river bank, a few rods farther southeast, at the top of this shale. Mr. Bowden reports another outcrop of a thin seam of lignite, perhaps belonging to the same layer, some 8 miles distant from this toward the south-southwest, occurring in a ravine tributary to the Sheyenne, about a mile west of its most southern bend. From the second to the first of these localities the river falls 20 feet, and these outcrops of lignite differ little in their elevation above the sea-level.

In the escarpment and plateau of Pembina Mountain.—Sections cut by the head streams of the Goose and Turtle rivers, in the highland between the Red River Valley and Devils Lake, and the similar erosion of the Pembina Mountain by the branches of Park River and by the Tongue, Little Pembina, and Pembina rivers, show that, beneath the drift, this long escarpment and the plateau which it bounds consist of dark, sandy shale, horizontal or nearly so in stratification, and nearly uniform in character for a great thickness. Gravel of this shale abounds in the channels of the streams for many miles east of the escarpment, and is found sparingly in the drift southward to the Coteau des Prairies. It is commonly called "slate" by the people of this region; but no portions observed possess the hardness and texture deserving this name, and no slaty cleavage is exhibited.

The highest outcrops of this formation seen by me, close to the west shores of Lake Agassiz, are on the plateau that extends westward from the top of the Pembina Mountain, where this is channeled by the North Branch of Park River in the vicinity of Milton. Along a distance of 5 miles from northwest to southeast through the north part of township 159 north, range 57 west, this stream cuts 75 to 125 feet into the shale, its top being 1,500 to 1,550 feet above the sea. It is overlain by only 5 to 25 feet of till, which continues equally thin, as shown by watercourses and wells penetrating to the shale, for 15 to 30 miles westward and northwestward, and, excepting two or three morainic belts, upon all the country southwest to Devils Lake. The surface about Milton is moderately undulating and rolling, with the crests of its higher portions 25 to 40 feet above the depressions. From this plateau an irregular descent, amounting to about 100 feet per mile, occupies the east part of this township and the edge of that next east, falling in 3 miles to the upper shore-line of Lake Agassiz, which here is approximately 1,200 feet above the sea.

The deepest part of the gorge of the North Branch of Park River is in sections 4, 9, and 10, township 159, range 57, where it is 125 to 150 feet deep and from a quarter to a half of a mile wide, with numerous fine exposures of the shale from the base to the top of the bluffs, except the thin capping of drift. In these places the stream, flowing at the base of the

bluff, removes the talus which elsewhere conceals its lower portion, and the section rises with cliff-like steepness at an angle of 60° to 75°. Excepting occasional thin beds, the whole thickness of the formation here exposed is hard gray shale, more or less sandy, divided into layers from an eighth of an inch to 2 or 3 inches thick, and much jointed, so that it crumbles into small fragments on the weathered surface. Rarely a bed a few inches thick, having the general dull-gray color, is harder and less jointed, owing to its cementation by carbonate of lime; and occasionally the ordinary shale is blackened by the deposition of iron rust and of manganese oxide as films in the jointage seams, the thickness of the portion thus colored being usually only a few inches, but in one place, half way up the north bluff, 3 or 4 feet. Gypsum was observed only in minute crystals in thin fissures coinciding with the planes of stratification, and in the form of satin spar, filling the mold from which some shell, commonly *Inoceramus*, has been dissolved away. Fossils are very infrequent, but by careful search *Baculites ovatus* Say and *Scaphites nodosus* Owen were found, each represented by a single specimen; also numerous *Inoceramus* casts, mostly *I. sagensis* Owen, besides casts and fragments of other lamellibranchs, not yet identified; and the teeth of fishes, apparently *Pachyrhizodus latimentum* Cope and *Lamna mudgei* Cope, or a smaller species.[1] The teeth occur somewhat plentifully in a remarkably hard layer, 6 inches to a foot thick, about 50 feet above the stream. With them this hard layer contains softer lumps, of somewhat irregular form, from one-third to three-quarters of an inch in diameter, of light-gray color inside, with a greenish exterior, which are probably coprolites. The other fossils were found in the shale fragments forming the talus, and their place in the section was not ascertained. Although few, they supply decisive evidence that this is the Fort Pierre formation.

The lowest exposure of this shale observed along the course of the Pembina Mountain in North Dakota is 21 miles north of the preceding, on the Pembina River, at the "fish trap," a rude weir of brush and poles, in the northeast corner of the northwest quarter of section 30, township 163, range 57. Here the river falls 7½ feet in about 40 rods, its elevation being

[1] For aid in the identification of these fossils, and of those collected on the Pembina River, I am indebted to Dr. C. A. White, of this Survey.

estimated about 1,050 feet above the sea. On each side, within a mile, the plateau of the Pembina Mountain, which the river cuts through, rises 400 to 450 feet higher. A bluff 150 feet high ascends steeply from the fish trap on the southwest side, and at the time of my first visit, in August, 1885, was newly exposed by slides, being shown to be fissile, dark-gray shale to the height of 100 feet, capped by glacial drift. The shale of this lower part of the Fort Pierre formation is more sandy, softer, and darker than that of its upper part, seen on the North Branch of Park River, and it further differs noticeably in having few joints. It is horizontally laminated, and, where it has been somewhat dried on the surface of the bluff, is easily separated in layers from a quarter of an inch to 1 inch thick; but at a depth of only 2 or 3 feet within its mass, where it is moist, no lamination is discernible. In this shale crystals of selenite 2 or 3 inches long are frequent, and the same mineral occurs in its crevices and seams. No lignite is found here, nor in any of the other outcrops of this formation along the whole extent of the Pembina Mountain to the south and north.

My second visit to this locality was made in August, 1886, to search for fossils, though none were found the year before. Only the upper 20 feet of the shale was visible in place at this later time, as the lower part, previously exposed almost to the level of the river, was concealed by the talus of fallen shale and drift. A portion of the shale beds 2 to 3 feet thick, about 10 feet below their top in this section and 90 feet above the river, not distinctly contrasted in color or texture with the beds above and below, was found to have an odor resembling that of petroleum, and to contain sparingly, on the planes of bedding, impressions of *Scaphites nicolletii* Morton, of which about a dozen specimens were collected, and occasional casts and fragments of *Inoceramus* and *Ostrea* species, one being probably *Inoceramus sagensis* Owen. From a mass of shale in the talus numerous cycloid fish scales, and a vertebral bone, $1\frac{3}{4}$ inches in diameter, belonging to some selachian fish, were obtained. If the formation is level in its stratification from south to north, as seems to be the case, this outcrop presents a portion of it approximately 200 to 300 feet lower than the bottom of its exposures on the North Branch of Park River.

About three-quarters of a mile east from the fish trap, this snale is exposed to a height of 75 feet above the Pembina River in a bluff on its northeast side. Its highest outcrop examined by me in this vicinity is Heart Mound,[1] a peculiar hillock with very steep sides and smoothly rounded top, situated on a broad, uneven terrace of Pembina Mountain, near the center of section 6, township 163, range 57, 3½ miles north of the fish trap and 2 miles south of the international boundary. The base and top of this hillock are, respectively, about 1,360 and 1,390 feet above the sea. Some have erroneously supposed it an artificial mound. Glacial drift, containing granitic bowlders up to 4 or 5 feet in diameter, thinly covers its northeast side; but the other sides and the crest of this knob consist of shale similar to that on the North Branch of Park River, showing that it is an outlier of the Fort Pierre beds that form higher land, drift-covered, about a mile westward. Heart Mound has been left thus isolated by the erosion of these beds from the surrounding area.

The thickness of the Fort Pierre formation in the northeast part of North Dakota, according to these observations, is at least 300 or 400 feet; but it doubtless considerably exceeds this, for there is no indication that these exposures mark its upper and lower limits. Wells in Langdon, 17 miles northwest of Milton and 1,610 feet above the sea, after passing through only 12 to 15 feet of till, enter this shale. With the underlying Niobrara and Fort Benton formations, which in this part of the State differ little in lithologic characters from the Fort Pierre, a thickness of 1,403 feet of dark-gray shales was penetrated by the Devils Lake artesian well before reaching the top of the Dakota sandstone, which there is 39 feet above the sea-level. In Fort Pierre outcrops on the North Branch of Turtle River, 1½ miles north of Niagara and about 1,375 feet above the sea, *Baculites ovatus* Say was found in abundance. The eroded eastern edge of the Fort Pierre shale forms the long, high escarpment of the "Second" Pembina Mountain, as the eroded border of the Pembina delta at Walhalla forms the almost equally notable, though much shorter, "First Mountain."

[1] Commonly called by English-speaking immigrants "the Indian Mound," but more properly named as above, in accordance with the usage of the French voyagers and residents, who, probably translating the aboriginal name, call this mound and the small area of prairie around it La Baie du Cœur.

But till or bowlder-clay, containing frequent granitic bowlders up to 5 or sometimes 8 feet in diameter, thinly covers the shale, so that good exposures of it are rarely seen, excepting in the bluffs cut by streams.

In western Manitoba and Assiniboia.—Dr. George M. Dawson gives the following summary of observations of the Cretaceous formations in the district bordering the west side of Lake Agassiz north of the international boundary, as obtained in the Geological Survey of Canada:

The character and thickness of the different members of the Cretaceous in the Manitoba region have not been worked out in detail, owing to the extent of the drift covering and scarcity of sections. * * * In the flat country of the Red River Valley no exposures of the Cretaceous rocks are found, and it is below the alluvium of this region that the older subdivisions probably occur. The western margin of the valley is formed by the escarpment of the second prairie steppe, and here, in the so-called Pembina Mountain, and in its continuation to the northwestward, the Cretaceous beds are first met with. About 25 miles north of the forty-ninth parallel, where the Boyne River cuts through the Pembina escarpment, beds clearly referable to the Niobrara group are known to occur, and precisely resemble, both lithologically and in their included fossils, those of the corresponding Nebraska division. The rock is generally a cream-colored limestone, chiefly composed of shells of *Inoceramus* and *Ostrea congesta*, but in places a white chalky material, which under the microscope is resolved into a mass of foraminiferal shells, coccoliths, and allied minute organisms. This exposure, though probably small in extent, enables the outcrop of the Niobrara to be defined at a point nearly 400 miles beyond the farthest northern locality known previous to its discovery. Still farther north, along the outcrop of the Cretaceous, at Swan River and Thunder Hill, west of Lake Winnipegosis, limestones and marls containing fossils like those of the last-mentioned locality, and evidently of Niobrara age, are again found, and other outcrops of these, and possibly of older beds, may probably be discovered in this vicinity.

With these exceptions, however, the Cretaceous rocks known to occur between the Red River Valley and the Lignite group of the Souris region belong exclusively to the Pierre group of the Cretaceous, while the Fox Hill group, which should intervene between this and the lignite-bearing series, has not in this district been recognized, and is, not improbably, but feebly developed. The Pierre rocks * * * consist of dark-colored grayish, bluish, or blackish shales, generally homogeneous in character through great thicknesses, and seldom containing fossils of any kind, though frequently charged with selenite crystals and holding nodular layers of poor limestone. Exposures of these beds are found in the Pembina escarpment on the Pembina River and its tributaries, and on the Assiniboine, where the thick drift deposits have been cut through. The clays or shales are generally quite characteristic in appearance, and

where they are found it may be taken for granted that the lignite-bearing formation has either been removed by denudation or has from the first been wanting. Though usually in appearance quite horizontal, these beds must have a slight westerly dip, which carries them beneath the Lignite group of the Souris River.[1]

Since this was written, Mr. J. B. Tyrrell has examined the Fort Pierre, Niobrara, and Lower Cretaceous formations in this district, as already cited, and has determined their thicknesses, chiefly made known by deep well borings. Rocks belonging to the Niobrara formation have also been examined and described by Director Selwyn, of the Geological Survey of Canada, on the southeast or right bank of the Assiniboine, in section 36, township 8 north, range 11 west, about 4 miles east from the mouth of the Cypress River, at an elevation approximately 950 feet above the sea. "The outcrop extends along the bank of the river for about 500 yards, and consists of beds of highly fossiliferous sandy limestones, brown freestone, and dark, almost black, soft shales. The sandstone and limestone, when broken or struck, emit a strong odor of petroleum."[2]

From my own notes of this locality I may add that the most conspicuous stratum, in which some quarrying has been done, is a light-yellowish, hard, sandy limestone, exposed from the low-water line of the river to a height of about 8 feet. It is horizontally stratified in layers from an inch to a foot in thickness. Fossil shells, chiefly *Ostrea congesta* Conrad, occur frequently throughout its whole thickness, being most abundant 3 or 4 feet below its top, where they sometimes form nine-tenths of the rock. With these are occasional specimens of *Belemnitella manitobensis*, a species recently described by Mr. Whiteaves.[3] This stratum along the greater part of its extent is overlain by till 20 feet or more in thickness, which in turn is overlain by the delta deposits of gravel and sand that the Assiniboine here brought into the west side of Lake Agassiz. But at the south end of its exposure, where the limestone sinks beneath the river, it is seen to be conformably overlain along a distance of some 25 rods by soft, dark shale, probably the base of the Fort Pierre formation, portions of which contain

[1] Geol. and Nat. Hist. Survey of Canada, Report of Progress for 1879–80, pp. 14, 15 A.
[2] Ibid., Annual Report, new series, Vol. I, for 1885, p. 38 A.
[3] Ibid., Contributions to Canadian Palæontology, Vol. I, p. 189, Pl. XXVI, 1889.

very abundant casts of *Inoceramus problematicus* Schlot. Scales of fishes are also found in both the limestone and shale.[1]

The Tiger Hills, extending westward from the north end of the Pembina Mountain, consist of the Fort Pierre shales, eroded in massive rounded elevations and overlain by drift from a few feet to 50 feet or more in thickness, much of which has the rough contour and abundant bowlders characteristic of terminal moraines. Thence southward to the international boundary the shale is frequently encountered at moderate depths in digging wells; and here and there remnants of its highest beds form isolated hills, which show that much erosion has taken place during a former baseleveling of the surrounding plain country. Pilot Mound, in section 20, township 3, range 11, about a third of a mile in diameter at its base and rising steeply 80 feet above the general level to a rounded summit about 1,630 feet above the sea, thus consists of the hard upper portion of this shale formation, thinly covered with drift. Star Mound, a more massive and moderately sloping elevation, situated in sections 22, 23, 26, and 27, township 1, range 10, about 15 miles southeast of Pilot Mound, is of the same character. The base of this hill extends three-fourths of a mile from east to west and a third of a mile or more from north to south; and it rises with a very regular oval form to a small plain 30 to 40 rods long from east to west and half as wide at its top, which is 100 feet above the adjoining country and about 1,650 feet above sea-level.

At the Niobrara outcrop on the Assiniboine the base of the Fort Pierre formation is about 950 feet above the sea; on the Vermillion River it is stated by Tyrrell to be at 1,205 feet; and on the Swan River it is probably not higher than 1,200 or 1,300 feet. Above these elevations the Fort Pierre shales form the upper portion of Riding and Duck mountains and of the Porcupine and Pasquia hills, reaching to the depth of several hundred feet beneath the glacial drift along the entire course of this great escarpment.

The records of common and artesian wells in Chapter X contain further notes of the Cretaceous formations underlying the drift on the Red

[1] My thanks are due to Mr. J. F. Whiteaves, of the Canadian Geological Survey, for his kind assistance in the identification of these fossils. A series of the variable small *Ostrea* obtained at this locality, and from the same formation on the Boyne and in the district of the Riding and Duck mountains and northward, was submitted by him to Dr. C. A. White, who refers them to *O. congesta* Conrad.

River Valley plain south and southwest of the Silurian area. Tracts of the Dakota sandstone probably supply the brackish water which is found by many wells in this valley, similar to the water derived from this sandstone by deep artesian wells at Tower City and Devils Lake, along the James River, and on higher land in South Dakota west of the James Valley.

FORMER EXTENT OF CRETACEOUS BEDS EASTWARD ON THE AREA OF LAKE AGASSIZ.

East from the foot of the highlands of Pembina, Riding, and Duck mountains and the hills farther north, Cretaceous strata have not been found, so far as I have learned, in Manitoba, nor in the region north and northeast from Lake Winnipeg to Hudson Bay. It seems quite certain, however, that Cretaceous beds continuous from this escarpment originally extended east a considerable distance, probably so far as to cover the area now occupied by Lake Winnipeg. As Hind and Dawson have pointed out, it was by the erosion of their eastern portion that this steep line of highlands was formed;[1] and it may be expected that thin remnants of them will yet be found in central and eastern Manitoba.

The eastward continuation of the Cretaceous formations in southern and central Minnesota, indicated by numerous outcrops, has been noticed in the preceding pages. Further evidence of their former extent is afforded in the north part of this State by Mr. Horace V. Winchell's discovery of Cretaceous shales in place on the Little Fork of Rainy River,[2] and by the frequent occurrence of lignite in the drift upon the country south of the Lake of the Woods and between Rainy Lake and Vermilion Lake. Possibly this lignite may be of interglacial age, like beds that are found between deposits of till in southeastern Minnesota, in the basin of the Moose River, tributary to James Bay, and in other places; but Prof. N. H. Winchell thinks that more probably its origin is from lignite-bearing Cretaceous

[1] H. Y. Hind, Report of the Assiniboine and Saskatchewan Exploring Expedition, Toronto, 1859, pp. 168, 169; Narrative of the Canadian Exploring Expeditions, London, 1860, Vol. II, pp. 48, 55, and 265. G. M. Dawson, Geology and Resources of the Forty-ninth Parallel, 1875, pp. 253, 254.

[2] Geol. and Nat. Hist. Survey of Minnesota, Sixteenth Annual Report, for 1887, pp. 403–9, 431, 434.

strata such as outcrop on the Sauk and Minnesota rivers. Concerning the eastern limits of Cretaceous beds in this State he writes:

> A line drawn from the west end of Hunters Island, on the Canadian boundary line, southward to Minneapolis, and thence southeastwardly through Rochester to the Iowa State line, would, in general, separate that part of the State in which the Cretaceous is not known to exist from that in which it does. It is not intended to convey the idea that the whole State west of this line is spread over with the Cretaceous, because there are many places where the drift lies directly on the Silurian or earlier rocks, but throughout this part of the State the Cretaceous exists at least in patches, and perhaps once existed continuously.[1]

SOURCES OF THE CRETACEOUS DEPOSITS.

Deposits of Cretaceous clay are found in waterworn hollows of the Lower Magnesian or Shakopee limestone forming the walls of the channel or valley of the Minnesota River at numerous places in Blue Earth, Le Sueur, and Nicollet counties. It is thus known that before the Cretaceous period, when western Minnesota and the region of the Upper Missouri were depressed and covered by the sea, a deep channel had been cut by some river in the Lower Silurian and Cambrian strata of the Minnesota Valley; but the small width of this channel indicates that the stream then flowing here, probably westward, was not larger than the present Minnesota River This and many other streams of similar size, flowing into the Cretaceous ocean as it spread to the east over the former land surface of Iowa, Minnesota, and Manitoba, contributed part of the detritus which made its vast mass of sediments, probably averaging a quarter of a mile in depth over most of its area. These beds could be supplied only by extensive and deep denudation upon the land areas both west and east of the Cretaceous mediterranean sea.

The very great disturbances of the region on the west in the elevation of the Cordilleran Mountain ranges, since the Cretaceous period, make it impossible to trace there the course of the larger tributaries to this sea. On the east half of the continent the principal drainage system, carrying its vast freight of detritus west to the Cretaceous ocean, is probably marked

[1] Bulletins of the Minnesota Academy of Natural Sciences, Vol. I, p. 348. Geology of Minnesota, Final Report, Vols. I and II.

by the chain of great lakes from Ontario to Superior, the west end of which is close to the east border of the submerged belt. At that time, and onward through the Tertiary era, much of this eastern land area appears to have been elevated at least several hundred feet above its present level, so that streams eroded the deep basins which are now occupied by these lakes, but then had a continuous westward descent. It seems probable also that other great tributaries may have flowed westward and southward into the Cretaceous sea, bringing sediments eroded from the areas of Hudson Bay, Lake Athabasca, and Great Slave and Great Bear lakes. The absence of Mesozoic and Tertiary formations on the east border of the continent north of the southern coast of New England shows that from the Gulf of Maine to Labrador and Hudson Bay the land during these eras stood higher above the sea-level than now. So long-continued high elevation, probably culminating at the beginning of the Glacial period, enabled streams to erode the fjords of Maine, Newfoundland, and Labrador, the gulf and estuary of the St. Lawrence, the deep channel of the Saguenay, and the broad straits and bays dividing the lands of the Arctic archipelago and separating them from Greenland.

DENUDATION OF THE CRETACEOUS AREA.

EROSION OF THE PLAINS TO A BASELEVEL.

Rains, rills and rivulets, creeks and rivers have been slowly but constantly wearing away the Cretaceous formations since their elevation above the sea and the drainage of the immense Laramie lake, which for a long period covered much of their area. When these marine and lacustrine deposits were first raised to be dry land, they had a monotonously flat surface; and they probably extended east, as we have seen, over the entire basin of the Red River of the North and of the great lakes of Manitoba, from which they now reach to the Rocky Mountains. The greater part of the present Cretaceous area, though eroded far below its original surface, is flat, undulating, or only moderately rolling, and constitutes a broad expanse of plains with very slow ascent westward. But here and there isolated areas of much higher hilly land, as the Turtle Mountain, consist of remnants of horizontal Cretaceous strata which elsewhere have suffered

denudation over all the surrounding country. The plains have been formed by the erosion of this vast area to a uniform baselevel, excepting only the isolated hilly tracts of comparatively small extent, which serve to show that on the eastern part of the plains, in North Dakota and southwestern Manitoba, a thickness of not less than 500 to 1,000 feet of the Laramie, Fox Hills, and Fort Pierre formations has been carried away. Around the Highwood and Crazy mountains, in central Montana, according to Prof. W. M. Davis[1] and Dr. J. E. Wolff,[2] the corresponding erosion of the plains in horizontally bedded Cretaceous formations has been 3,000 to 5,000 feet.

When the depth and great extent of this denudation are compared with those of the subsequent erosion which formed the Red River Valley and the lowland adjoining the Manitoba lakes by the removal of the former eastern part of the Cretaceous plains to the limit of the great escarpment west of Lake Agassiz, the early baseleveling seems probably to have occupied the Eocene and Miocene periods, with nearly all of the Pliocene, comprising nine-tenths or a longer portion of the whole Tertiary era. Its duration apparently coincided, as to both beginning and end, with the Tertiary or Somerville cycle of partial baseleveling which Davis and Wood have studied in Pennsylvania and northern New Jersey and believe to have affected a large area of the other Eastern States.[3] The termination of the denudation forming the plains of the Cretaceous area, and their uplift to undergo the erosion of the Red River Valley and of the present Assiniboine and Saskatchewan valleys, were probably also contemporaneous with the great epeirogenic[4] movement which in California, according to Mr. J. S. Diller, ended a long cycle of baseleveling that had extended through the whole of Cretaceous and Tertiary time, and raised a part of that baseleveled district at the beginning of the Quaternary era to form the lofty

[1] Mining Industries of the United States, Tenth Census, Vol. XV, pp. 710, 737, 745.

[2] Notes on the Petrography of the Crazy Mountains and other localities in Montana Territory, p. 16. Bull. Geol. Soc. Am., Vol. III, 1892, pp. 445–452.

[3] National Geographic Magazine, Vol. I, 1889, pp. 183–253; Vol. II, 1890, pp. 81–110. Proceedings, Boston Society of Natural History, Vol. XXIV, 1889, pp. 365–423.

[4] A term proposed by Gilbert, equivalent with continent-making. "The process of mountain formation is *orogeny;* the process of continent formation is *epeirogeny*." U. S. Geol. Survey, Monograph I, Lake Bonneville, 1890, p. 340.

Sierra Nevada.[1] Again, the same record of long-continued baseleveling, followed by uplift and a new cycle of rapid valley erosion, is found by Powell and Dutton in the plateaus and Grand Canyon of the Colorado.[2] The denudation above these plateaus, when compared with the studies thus noted in other regions and with the total erosion of the canyon, seems to have required not only the Eocene and Miocene periods but also most of the Pliocene; for the ratio of the denudation to the canyon-cutting must be nearly or quite as great as that between the duration of the entire Tertiary era and the comparatively short time since its close. Instead of referring the division of these parts of the history of the Grand Canyon district to the beginning of the Pliocene, as was done provisionally by Dutton, it may therefore mark the final stage of the Pliocene and the inauguration of the Glacial period, with high elevation of all the northern part of this continent and of the glaciated northwestern portion of Europe.[3]

LATER EROSION OF THE TROUGH OF LAKE AGASSIZ.

At the time of uplifting of the plains near the end of the Pliocene period, this great baseleveled region appears to have stretched from the Rocky Mountains to the Archean hills on the eastern border of Lake Agassiz, and to have included also the expanse of flat or only moderately undulating country which slowly falls from Lake Winnipeg and the upper part of the Nelson River toward Hudson Bay. The Tertiary drainage of this district, from the present sources of the Saskatchewan, Red, and Rainy rivers to Hudson Bay and Strait, probably formed a great river flowing through the Appalachian-Laurentide mountain belt in the deep valley which is now submerged to form this strait, and emptying into the Atlantic between Labrador and Cape Farewell. The depression of the lower part of this basin beneath the sea seems to me referable to the time of the culmination and departure of the Quaternary ice-sheet. Between the Ter-

[1] U. S. Geol. Survey, Eighth Annual Report, pp. 428–432. Compare also articles by Prof. Joseph Le Conte, Am. Jour. Sci. (3), Vol. XIX, pp. 176–190, March, 1880; Vol. XXXII, pp. 167–181, Sept., 1886; Vol. XXXVIII, pp. 257–263, Oct., 1889.

[2] Exploration of the Colorado River of the West, 1875. Geology of the eastern portion of the Uinta Mountains, 1876. U. S. Geol. Survey, Monograph II, Tertiary History of the Grand Cañon District, 1882. Am. Jour. Sci. (3), Vol. XXXII, pp. 170, 171, Sept., 1886.

[3] Am. Geologist, Vol. VI, pp. 327–339, 396, Dec., 1890. Am. Jour. Sci. (3), Vol. XLI, pp. 33–52, Jan., 1891; Vol. XLVI, pp. 114–121, Aug., 1893.

tiary baseleveling and this subsidence a widely extended epeirogenic uplift of North America intervened. To this period of late Pliocene and early Quaternary elevation belong the erosion of the canyons of the Colorado and its tributaries, of the canyons on the slopes of the Sierra Nevada, and much river channeling of the plains east of the Rocky Mountains.

The eastern margin of these plains, which probably extended, as before noted, over the whole area of Lake Agassiz, was then subjected to renewed erosion, removing the mostly soft Cretaceous strata upon a width of a hundred miles or more and to a depth westward of several hundred feet. Previous to this new cycle of active work by the streams, Riding and Duck mountains stood above the general level, like Turtle Mountain and other isolated high areas farther west; and the maximum depth of the late stream-cutting by which the trough of the Red River Valley and Lake Agassiz was formed is approximately measured by the height of the Pembina Mountain escarpment, which rises 300 to 400 feet from its base to its crest along its extent of about 80 miles. The greater part of this erosion we must attribute to the probably long time of elevation preceding, and finally at its climax producing, the ice-sheet of the Glacial period. So far as can be discerned, the entire hydrographic basin of Lake Agassiz may have continued, through all these vicissitudes of changes of levels, excepting when it was wholly or partially ice-covered, to be drained in the same north and northeast direction as during the Tertiary era and at the present day.[1]

In the progress of denudation by the Tertiary baseleveling and by the later erosion of the hollow which was to hold Lake Agassiz, some of the Cretaceous strata have proved more durable than those next above and below, and consequently have had a more important influence on the topography. This is especially noteworthy in the case of the Fort Pierre formation, which forms the upper and main part of the great escarpment that borders the west side of Lake Agassiz from the Coteau des Prairies north-northwest to the Saskatchewan River. East of the Red River Valley in Minnesota the similar but less prominent ascending slope from the flat

[1] Am. Geologist, Vol. XIV, pp. 235–246, Oct., 1894. Bulletin Geol. Soc. of America, Vol. VI, pp. 17–20, Nov., 1894.

valley plain doubtless also consists of Cretaceous shales, perhaps chiefly the Niobrara and Fort Benton formations, beneath the envelope of glacial drift. Farther east and southeast, through northern and central Minnesota, it seems certain that at least many Cretaceous knobs and hills thus far had escaped the general Tertiary and early Pleistocene denudation, but most of them were leveled during the Ice age and mingled with the glacial drift. Westward from the Pembina and Manitoba escarpment the Fort Pierre formation generally constituted the preglacial surface, and is now the floor on which the drift lies, until it is succeeded by the Laramie series. This again includes especially enduring beds, which have caused the preservation of extensive outlying areas, as the Turtle Mountain and probably other masses of hills farther north, situated many miles east of the principal Laramie outcrop. In the same way that the Fort Pierre formation makes the escarpment west of the valley of the Minnesota and Red rivers and the Manitoba lakes, the Laramie beds, underlying the drift, make the greater part of the equally prolonged terrace-like highland of the Coteau du Missouri from South Dakota northwesterly through North Dakota, Assiniboia, and Saskatchewan. Numerous outliers exist, however, east of the main course of this coteau, in the region crossed by the North Saskatchewan River.

The course of the preglacial rivers flowing from the Cretaceous area west of Lake Agassiz, after the late Pliocene uplifting of the continent, probably coincided approximately with the present avenues of drainage throughout the region north of the international boundary, in the Assiniboine, Saskatchewan, and Athabasca basins. In North and South Dakota, the present channel of the Missouri River, as shown by Gen. G. K. Warren[1] and by Prof. J. E. Todd, dates only from the Glacial period, this great stream having been turned aside by the ice-sheet to the west and south from its preglacial course, which may have occupied the valley of the James or Dakota River, nearly parallel with the Missouri of to-day, or perhaps continued east to the most southern bend of the Souris River, or to the Sheyenne and Red rivers. Professor Todd finds also in the topography of that region evidence that in preglacial time the great tributaries coming from the west to join this part of the Missouri, namely, the Cannon

[1] Annual Report of the Chief of Engineers, U. S. Army, for 1868, pp. 307-314.

Ball River, the Grand and Moreau rivers, then united, the Cheyenne, and the White River, flowed east to the James Valley; and he is inclined to believe that from that valley the great stream formed by these affluents passed northeast to the Red River of the North and Hudson Bay.[1] That the greater part of the excavation of the trough of Lake Agassiz could be accomplished by a river of such size during the Lafayette period of continental elevation, following the Pliocene period and inaugurating the Ice age, may be readily believed when we compare it with the Lafayette erosion of the Mississippi, which from Cairo southward, along an extent of about 500 miles, formed a channel 200 to 300 feet deep and averaging 60 miles wide.[2]

Tertiary and early Quaternary erosion had sculptured the grand features of the basin of Lake Agassiz, and its whole extent probably had approximately the same contour immediately before the accumulation of the ice-sheet as at the present time. The surface of the feldspathic Archean rocks was doubtless in many places decomposed and kaolinized as it is now seen where they are uncovered in the Minnesota Valley, and as such rocks are frequently changed to a considerable depth in regions that have not been glaciated. On these and all the other rock formations the ordinary disintegrating and eroding agencies of rain and frost had been acting through long ages. Much of the loose material thus supplied had been carried by streams to the sea, but certainly much also remained and was spread in general with considerable evenness over the surface, collecting to the greatest depth in valleys, while on ridges or hilltops it would be thin or entirely washed away. Except where it had been transported by streams and consequently formed stratified deposits, the only fragments of rock held in this mass would be from underlying or adjoining rocks. The surface then probably had more small inequalities than now, due to the irregular action of the processes of weathering and denudation, which are apt to spare here and there isolated cliffs, ridges, and hillocks; but most of these minor features of the topography have been obliterated by glacial erosion or buried under the thick mantle of the drift.

[1] Proc., A. A. A. S., Vol. XXXIII, 1884, pp. 381–393, with map.

[2] Am. Naturalist, Vol. XXVIII, pp. 979–988, Dec., 1894. Bulletin, Geol. Soc. of America, Vol. V, 1894, pp. 87–100.