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The Geology and Ground Water Resources of the Emerado Quadrangle

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CONTENTS

ILLUSTRATIONS

TABLES

Geology and Ground Water Resources of the Emerado Quadrangle

— *by* —

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INTRODUCTION

Abstract

The glacial geology of the Emerado area was mapped and studied in detail. It was found that the glacial deposits in the area consist of till, laminated lake clays, lake silt, beach gravels, and so-called "delta" or outwash deposits. The evidence is suggestive of two distinct periods of deposition in the Lake Agassiz basin. A well census of the water wells within the quadrangle was made from which it was learned that in the "delta" area the water is in general 5 - 15 feet deep, and on the beaches 6 - 15 feet deep. Some of the wells, particularly in the eastern part of the quadrangle, are artesian wells both of the Red River valley and Dakota artesian systems. These range from 18 - 412 feet deep.

Purpose and Scope of the Investigation

The main purpose of the investigation was the mapping of the glacial geology of the Emerado quadrangle and the delimiting of the ground water conditions in the area. In the geologic mapping, the topographic map of the Emerado quadrangle as surveyed by the United States Geological Survey was used as a base map. The topography is shown on this map by 10 foot contour lines so that minor topographic features were usually repreesnted. The contacts of the various formations were sketched in on this map after running the roads on the section lines with a car to get approximate distances from known points.

The well data was gathered by Mr. Michael Chernich, my assistant, and was recorded on sheets similar to those used by the United States Geological Survey. Whenever possible, he measured the wells himself. When not possible due to well construction or other reasons the word of the occupant of the farm was taken.

Location of the Area

The Emerado quadrangle is located between 97°15′ and 97°30′ west longitude, and between 47°45′ and 48°00′ north latitude in the east-central part of Grand Forks County. The organized townships of Chester and Pleasant View are entirely within the boundaries of the map. Most of the organized townships of Fairfield, Oakville, Blooming Valley, and Mekinock are found in the quadrangle. Small parts of Hegton, Arvilla, Avon, Washington, and Union townships are included on the west and south boundaries of the area. The quadrangle is approximately 11¾ miles in an east-west direction by 17½ miles in a north-south direction. Approximately 205 square miles are included within the boundaries of the quadrangle.

Previous Investigations

Of all the previous work in this area, that of Warren Upham[1] stands first. Upham's report deals with the whole Lake Agassiz basin but he describes the area of this report specifically.[2] Upham gives references in his monograph to early workers and explorers who visited this area and published their findings so these need not be repeated here.

Frank Leverett in his work[3] adds to that of Upham particularly in publishing more detailed maps and furnishing additional data not available to Upham.

H. E. Simpson, former State Geologist, compiled considerable information on the ground water conditions in this area for the Ground Water Division of the United States Geological Survey.[4]

From 1937 to 1940 a statewide Works Progress Administration ground water study was carried on in cooperation with the North Dakota Geological Survey. This project gathered data on approximately 58,000 water wells all over North Dakota. A summary of this data including that of Grand Forks County was published in mimeographed form.[5] The complete data are on file in the North Dakota Geological Survey office in Grand Forks.

Acknowledgements

Mr. Michael Chernich, student assistant, collected all of the well data in this quadrangle and also assisted in the geologic mapping. The many residents of the area courteously gave much information and help in the gathering of the well data. Mr. Russell Reid, Superintendent of the State Historical Society and Mr. Albert Thoren, Custodian of the Turtle River State Park provided a cabin for the use of the State Geologist and assistant during the field work. Mr. Arthur L. Greenlee, Assistant Geologist of the United States Geological Survey, kindly read the section on ground water and made helpful suggestions. Great credit is due Dr. J. S. Templeton, formerly of the Department of Geology of the University of North Dakota for outlining the geology of the area and doing part of the mapping.

GEOGRAPHY

Physiographic Position

The Emerado quadrangle lies within the limits of the Western Young Drift Section of the Central Lowland.[6] The Central Lowland

[1] Upham, Warren, The Glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, 658 pp. 1896.
[2] **op cit.** pp. 333-336, 390-391, 403, 418, 436-437, 456, 460-461, 573.
[3] Leverett, Frank, Quaternary geology of Minnesota and parts of adjacent states: U. S. Geol. Survey Prof. Paper 161, 149 pp. 1932.
[4] Simpson, H. E., Geology and Ground Water Resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, pp. 135-140, 1929.
[5] Survey of Water Supplies, Parts I and II: North Dakota Geological Survey in cooperation with the Works Progress Administration, Grand Forks, North Dakota, July 11, 1940.
[6] See Fenneman, N. M., Physiography of Eastern United States, pp. 559-588, New York, McGraw-Hill Book Co., 1938. This is comprehensive treatment of the whole area.

consists of an area of 585,000 square miles wholly or partly covering 16 states. It ranges in elevation from 1800 feet on its western border to 450 feet on its southeastern border and to 300 feet on the shores of Lake Ontario. "The lack of major distinction in this great area is due in part to its nearly flat-lying rocks. Glaciation dominates most of the landscape, but it probably created as much variety as it destroyed." [7]

The distinguished feature of the Western Young Drift area is the presence of youthful glacial drift overlying a glacially-smoothed bedrock surface. The drift in much of the area is irregular morainal topography which gives rise to numerous lakes. These lakes in the more humid area such as in Minnesota are fresh water but those in the semi-arid regions of central and northwestern North Dakota are frequently saline.

Some of these lakes have not existed within historical time. Such a lake was Glacial Lake Agassiz whose former bottom now includes most of the Red River valley area. This former lake had an area of 110,000 square miles, mainly in Canada, but covered about 15,000 square miles of Minnesota and 6,800 square miles of North Dakota.[8] The area under discussion is included within the boundaries of former Lake Agassiz.

The Lake Agassiz area in North Dakota consists of a broad flat plain sloping gradually northeastward. The present day northward slope of the plain is less than one foot per mile. Surmounting the plain in North Dakota are generally low northwestward-trending beach ridges which rise 8 or 10 feet above the general level of the plain. These ridges are not continuous from one end of the lake area to the other but the same beach is usually traced with little difficulty.

Since the ice receded from this area there have been slight orogenic movements which differentially uplifted the northern part of the lake area. This caused the elevation of the beaches, particularly the higher Lake Agassiz beaches, to increase to the northward.

Surface Features

Delta

In the southwestern corner of the Emerado quadrangle is an area underlaid by fine sand and silt of the so-called Elk Valley "delta." This area has an elevation of 1050-1100 feet above sea level in this quadrangle. It lies approximately 30 feet above the general level of the old lake bottom. In the west-central edge of the map the line of demarcation between the "delta" and the old lake bed is in the form of a distinct but low escarpment.

The surface of the "delta" is rolling and is crossed by representatives of the Norcross and Tintah beaches. These beaches here are not gravel covered but show only the low rounded beach form. Due to the sandy nature of the sediment composing the delta, it "blows"

[7] Fenneman, **op. cit.** p. 449
[8] Fenneman, **op. cit.**, p. 579.

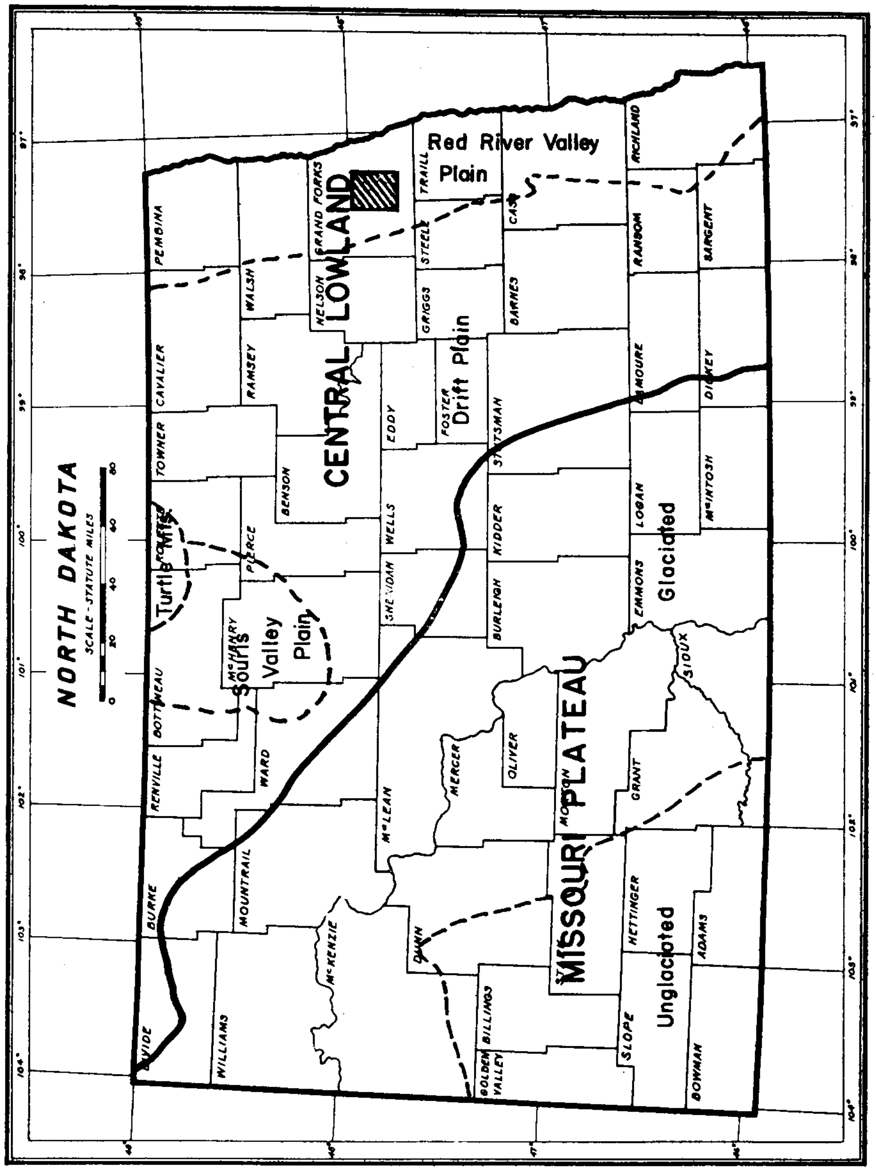

Fig. 1. Sketch map showing location of the Emerado Quadrangle and the physiographic provinces found in North Dakota.

badly when exposed to vigorous wind action. Dunes are formed in such places as can be seen in the SE¼ of the NE¼ of Section 20, T. 150 N., R. 53 W.

Beaches

The beaches of old Lake Agassiz are the most prominent topographic features in the Emerado area. In addition to the beaches of the Norcross and Tintah stages already mentioned, the beaches of the Campbell, McCauleyville, Blanchard, Emerado and Ojata stages are also found.

Generally speaking, the beaches are low rounded ridges usually 300 to 400 feet in width trending in a northwest-southeast direction. Some of the beach ridges are wider, particularly where two of the beaches come together as in the SW¼ of Section 29, T. 150 N., R. 53 W. where the Campbell and McCauleyville beaches are joined together. The ridges stand 10 to 15 feet above the general level of the old lake bottom with the steepest side, usually on the northeast or lake side, but this is not always so. Some of the beaches are multiple in that they are found at the same elevation but are separated by a few yards from each other. Probably some of these multiple beaches were offshore bars in the lake and were formed at the same time as the beach. The beaches have been little modified by erosion since the lake left the area except near the Turtle River where the river itself and some of its tributaries have modified them slightly. The beach ridges, while trending in a northwesterly driection, are not always continuous. This may be due to later erosion but more probably is due to original irregular deposition.

Till, clay, and silt area

The till, clay, and silt area is the most extensive of any of the separate physiographic sub-units delimited in this quadrangle. This sub-unit is, in general, quite flat, sloping (with the exception of the intervening beaches) gently to the northeast at the rate of approximately 13 feet per mile. In the central part of the area underlain by the till the surface is covered by wind blown sand to a depth of 12 to 18 inches. Farther to the northeast, there is less sand so that the till and clay are at the surface. In the extreme northeastern corner, the clay is covered by the silt which does little to modify the topography. The till areas are poorly drained particularly in the east-central part of the quadrangle where it is left mainly in pasture and meadow.

River terrace

Immediately adjacent to the Turtle River is a relatively flat terrace area from 10 to 20 feet above the present stream. The terrace is, for the most part, composed of fine grained material deposited by the river. Irregularities on the surface of the terrace are due largely to erosion and irregular deposition when the stream was flowing at the level now represented by the terrace. The terrace slopes downstream at the rate of approximately 6 feet per mile. The terrace is about 10 to 20 feet below the upland level of the till. The sediments rest on a terrace cut in the underlying till but nowhere in the quadrangle is this cut terrace exposed at the surface.

Generally speaking, the width of the terrace decreases downstream from about one-half a mile in width on the boundary line between Sections 29 and 30, T. 152 N., R. 53 W. to about one-eighth mile in width in the NE¼ Section 15, T. 152 N., R. 53 W. For some reason the terrace is widest where it cuts through the Blanchard beaches. It is narrower above and below that point.

Kelly Slough

In the northeastern corner of the map is a peculiar depression locally called Kelly Slough. This irregularly-shaped depression is shaped roughly like a normal stream system and its tributaries. However, it is not a stream valley but a swamp and it is only toward its northeasterly continuation that it begins to be occupied by an intermittant stream.

The slough is flat bottomed with its greatest width (about one mile) normal to its axis. In other places it is less than one-fourth mile in width. The sides of the slough are steep and, in general, the slough bottom is 10 to 20 feet below the upland level. Salt water springs are numerous in the bottom of the depression. The shape of the slough and the presence of numerous springs suggest that the depression owes its shape and origin to sapping of the banks by the spring waters.

Drainage

The area is poorly drained as a well-integrated drainage system, with the exception of the immediate vicinity of the Turtle River, has yet to be established. The streams of this region all flow in a generally northeasterly direction with the slope of the land surface. They are consequent streams and have been developed since the glacier and Lake Agassiz left this area. The largest stream within the boundaries of the quadrangle is the Turtle River, which within the boundaries of the map, has a gradient of approximately 6½ feet per mile. While the Turtle River is apparently still actively downcutting, it does have a very sinuous course. In normal years the Turtle River does not flow the entire year and is therefore noted on the map as being an intermittant stream.

The other streams of the quadrangle are all intermittant streams. The source of water of some of these, such as Freshwater Creek, can be found in springs and seeps along their banks and in the stream bottoms. Much of this water is derived from the Red River valley artesian system which is discussed later in this report. There are also a few old abandoned flowing wells in this vicinity such as the one located in the SE¼ Section 23, T. 151 N., R. 52 W., which furnish considerable quantities of water to these streams.

Development

Agriculture

The area included in this quadrangle is almost entirely devoted to some phase of agriculture, either farming or grazing. In general it can be said that farming is most general over the whole area except for the small triangular area south of the Great Northern Railroad and east of Emerado. The hypotenuse of the triangle is roughly the Emerado beach which limits the area on the southwest. Within this area, the soil is a heavy clay and often water soaked from the waters rising from the Red River valley artesian system. These waters are heavily mineralized giving rise to alkali spots in which little or no vegetation grows. This triangular area is almost exclusively utilized as pasture and hay land.

Communications

The area is served by the main line of the Great Northern Railroad and by United States Route 2 which is a bituminous-surfaced highway. There are graded county and township roads on nearly every section line making any part of the area relatively easy of access. Some of these graded roads have not been worked of late years due to lack of use and therefore on some of them the small bridges are in bad order.

Resources

Other than a fertile soil, the main resources of this area are extensive gravel deposits and large quantities of highly mineralized artesian water.

Gravel

While all the beaches have some gravel on them only the Campbell, McCauleyville, Blanchard, Hillsboro, and Emerado have sufficient quantities to be considered. Of the beaches mentioned most gravel now removed in the area comes from the McCauleyville, Campbell, and Blanchard beaches. Mr. R. J. Bradshaw,[9] the operator of the only commercial gravel pit in the quadrangle, reports that about 40,000 cubic yards of gravel are removed from his pits each year. He says that the average pit run gravel is clean enough for any cement work but that when washed gravel is called for it is supplied in that fashion.

Methods used in making the mechanical analysis

In the field relatively large samples of the gravels were taken. After these samples dried, they were quartered down so that 1000 grams remained. The 1000 grams were placed in Tyler screens and shaken by the Tyler automatic "Ro-Tap" shaker for a period of 15 minutes. This unit of time seemed the most satisfactory for these gravels. Larger samples had to be taken because of the presence of much coarse material. After shaking, the residue left on each screen was weighed accurately on a balance and the percentage of the total sample retained on each screen was calculated.

Observations on the gravel analysis

For the sake of uniformity Wentworth's size classification was

[9] Letter of January 18, 1944.

used. This classification and the name of the particle sizes is given below.

Grade limits Diameter in mm.	Name of particles
Above 256	Boulder
256 to 64	Cobble
64 to 4	Pebble
4 to 2	Granule
2 to 1	Very coarse sand
1 to ½	Coarse sand
½ to ¼	Medium sand
¼ to ⅛	Fine sand
⅛ to 1/16	Very fine sand
1/16 to 1/256	Silt
Below 1/256	Clay

Preliminary screening showed that most of the material fell within the sizes of 4 to ⅛ mm. in diameter so the following Tyler screens were used: 9 mesh (1.98 mm.), 16 mesh (.991 mm.), 32 mesh (.495 mm.), 60 mesh (.246 mm.), 115 mesh (.124 mm.), 250 mesh (.061 mm.) and the bottom pan. These sizes conform most closely to the Wentworth grade scale which was used in plotting the data.

While not within the limits of this type of report it is interesting to note that there is some similarity between the graphs of gravels taken from the same beach. For example, it will be noted by referring to Figure 2 that samples 1, 2, and 3 taken from the Campbell beach show higher percentages of material above 2 mm. in diameter than the samples from other beaches. It will also be noted that sample 9 and 10 taken from the Hillsboro beach show higher percentages of material between ¼ and ½ mm. in diameter than most of the others. It will be noted in all cases that most of the material is above ¼ mm. in diameter. This is to be expected in beach gravels where constant wave action removes most of the finer material.

The few analyses made in this report are not sufficient in number so that any valid conclusions can be drawn. They do, however, suggest that more work could profitably be done. The analyses suggest that different sizes of material could more readily be found on one beach than another. This fact should be useful if one was looking for a certain size gravel for a particular purpose.

The analyses also suggest that there is a correlation between the size of gravel and the amount of time the waves had to operate on any beach. It will be noted that the coarsest material is in the Campbell beach which is the most prominent beach in the Lake Agassiz basin and the one which undoubtedly experienced the most severe and prolonged wave action. Unquestionably, the availability of certain size material as well as current action and probably numerous other factors at present unknown all affected the distribution of the various size materials.

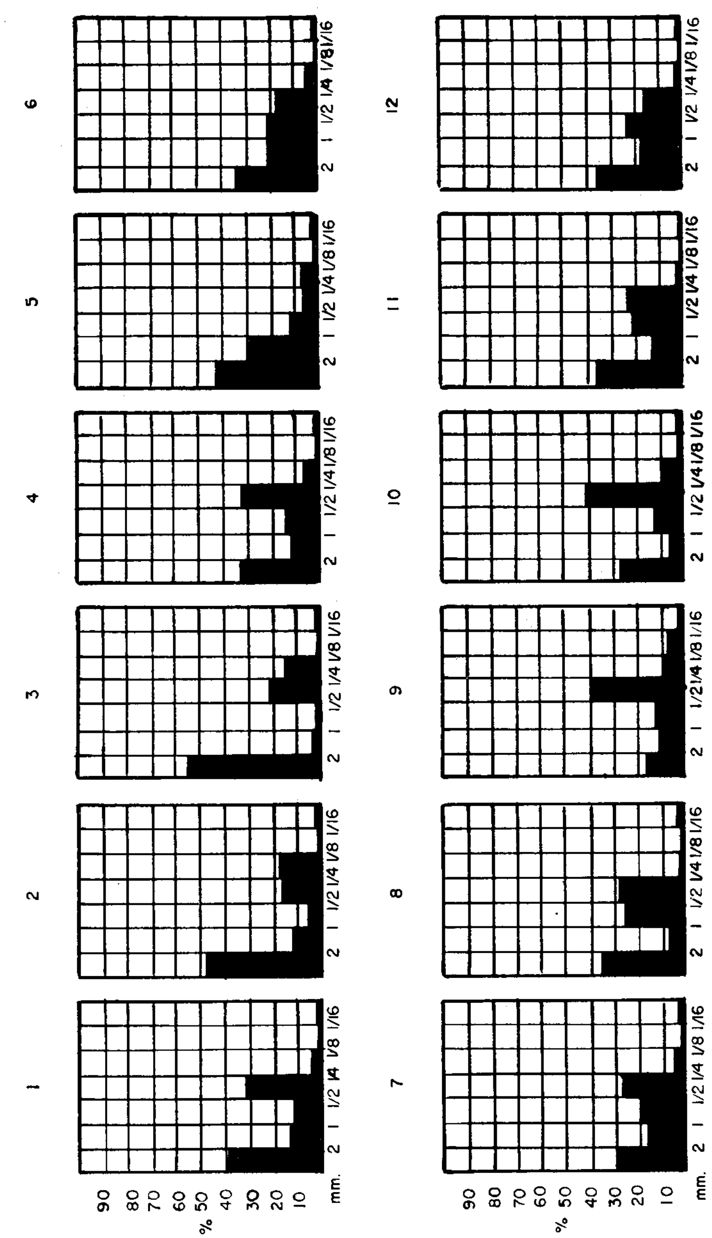

Fig. 2 Graphs of selected gravel analyses.

TABLE I

Location of gravel samples taken for mechanical analysis (See Figure 2)

1.	NE¼	Section 6, T. 149 N., R. 52 W.	Campbell beach
2.	SE¼	Section 31, T. 150 N., R. 52 W.	Campbell beach
3.	NW¼	Section 32. T. 150 N., R. 52 W.	Campbell beach
4.	NE¼	Section 11, T. 150 N., R. 53 W.	McCauleyville beach
5.	SE¼	Section 32, T. 150 N., R. 52 W.	McCauleyville beach
6.	SW¼	Section 20, T. 150 N., R. 52 W.	McCauleyville beach
7.	NW¼	Section 15, T. 151 N., R. 53 W.	Blanchard beach
8.	NE¼	Section 22, T. 152 N., R. 53 W.	Blanchard beach
9.	NW¼	Section 24, T. 151 N., R. 53 W.	Hillsboro beach
10.	SW¼	Section 25, T. 151 N., R. 53 W.	Hillsboro beach
11.	SW¼	Section 21, T. 151 N., R. 52 W.	Emerado beach
12.	SE¼	Section 20, T. 151 N., R. 52 W.	Emerado beach

Climate

General

This area is part of the region having what is known as a Humid Microthermal climate with a short summer phase.[10] This is sometimes known as the "spring wheat" climate because this crop reaches its best development in the drier parts of this climatic phase. There is an extreme change of temperature from summer to winter. The growing season is from three to five months in length but the longer periods of sunshine in the higher latitudes somewhat offset the disadvantage of a short growing season. The precipitation is commonly less than 25 inches, coming mainly as rain during the summer months. The snowfall is usually slight particularly near the drier margins of this phase.

The Emerado quadrangle unfortunately does not have adequate climatic data from any stations within its borders. However, statistics on precipitation and temperature are available at Larimore and Grand Forks. The Emerado quadrangle is almost halfway between these two stations.

Precipitation

For precipitation data reference should be made to Table II which is the record of 50 years from 1893 to 1942 inclusive. During the period of this record, Grand Forks had more precipitation than Larimore during 25 years. During the other 25 years Larimore had more precipitation than Grand Forks. The lowest precipitation recorded for Grand Forks was 9.38 inches in 1910. The lowest for Larimore was 7.68 inches in 1936. The highest amount of precipitation for Grand Forks was 26.80 inches in 1941; for Larimore 33.78 inches in 1921. The average precipitation for the 50 year period for Grand Forks was 19.43 inches; for Larimore 20.256 inches.[11]

[10] See Trewartha, G. T., An introduction to Weather and Climate, pp. 313-319, 1937.

[11] All climatic data in this report were derived from publications of the United States Weather Bureau kindly loaned to the writer by Miss Vernice Aldrich, Special Climatological Observer at the University of North Dakota.

TABLE II

ANNUAL PRECIPITATION FOR THE YEARS 1893-1942 INCLUSIVE FOR GRAND FORKS AND LARIMORE

YEAR	GRAND FORKS	LARIMORE	YEAR	GRAND FORKS	LARIMORE
1893	17.97	17.81	1918	20.31	20.80
1894	18.70	15.49	1919	23.01	25.32
1895	18.64	14.78	1920	12.93	19.79
1896	26.10	22.55	1921	18.21	33.78
1897	17.40	15.42	1922	22.83	33.14
1898	23.19	15.50	1923	18.88	23.27
1899	19.65	13.45	1924	20.52	27.56
1900	20.04	19.58	1925	25.03	24.73
1901	26.40	19.67	1926	18.57	21.78
1902	22.00	23.35	1927	23.20	25.89
1903	17.79	19.69	1928	19.43	25.54
1904	20.98	22.75	1929	16.39	21.85
1905	25.17	21.66	1930	21.39	22.13
1906	18.15	19.62	1931	19.49	20.80
1907	15.97	19.97	1932	17.87	21.88
1908	17.40	17.20	1933	15.38	15.23
1909	15.42	16.75	1934	14.75	13.65
1910	9.38	13.02	1935	21.89	20.33
1911	23.18	33.67	1936	9.91	7.68
1912	20.75	20.43	1937	23.03	18.44
1913	14.14	16.81	1938	18.86	16.07
1914	23.31	19.77	1939	16.67	11.75
1915	19.40	18.65	1940	19.14	22.18
1916	22.62	26.42	1941	26.80	23.61
1917	13.65	12.68	1942	19.63	18.95

Table III gives the average monthly precipitation for the years 1891-1930 inclusive for Grand Forks and 1893-1930 for Larimore.

While none of this data is for the Emerado area directly it is believed that they are geographically near enough to be significant. It will be noted that only during the four months of May, June, July, and August was the precipitation greater than two inches for the month. For both Grand Forks and Larimore the greatest rainfall occurred during June. According to Trewartha[12] "most of the warm season rainfall is convectional in origin, although drizzly cyclonic days are more frequent than farther south."

Temperature

For temperature data reference can be made to Table IV which gives the maximum, minimum and average annual temperatures for

[12] op. cit. p. 317.

TABLE III

AVERAGE MONTHLY PRECIPITATION FOR GRAND FORKS AND LARIMORE

For the years 1891-1930 inclusive the average monthly precipitation at Grand Forks is as follows:

January	.54	July	2.73
February	.58	August	2.48
March	.73	September	1.85
April	1.84	October	1.27
May	2.61	November	.81
June	3.42	December	.63

For the years 1893-1930 inclusive the average monthly precipitation at Larimore is as follows:

January	.65	July	3.23
February	.58	August	2.64
March	.76	September	2.08
April	1.68	October	1.37
May	2.76	November	.87
June	3.94	December	.57

the years 1914-1942 inclusive. It can be seen from the table that there is a fairly close relationship between the annual temperatures of the two localities. The highest temperature for Grand Forks was 109° in July in 1936; the lowest recorded temperature was -42° in the month of February in 1936. The highest temperature recorded for Larimore was 111° in the month of July in 1936; the lowest temperature was -41° in the month of February in 1936. The average annual temperature for the 26 year period for Grand Forks was 39.18°; for a 29 year period for Larimore was 39.15°

GEOLOGY

General

In the Emerado quadrangle there are no bedrock exposures, the whole area being covered with glacial drift. Relatively little is known of the bedrock immediately in this area except that a few wells have penetrated to the Dakota sandstone. However, well data from Grafton approximately 33 miles to the north and Glenfield approximately 65 miles to the southwest indicate the presence of lower Paleozoic strata. Paleozoic rocks are not exposed at the surface anywhere in North Dakota. It is reasonable to assume that such strata underlie this area although no direct evidence of them is available.

Mesozoic strata are observable in the Pembina Mountain area about 50 miles north of Emerado where the Benton, Niobara and Pierre formations are exposed. The nearest exposure to Emerado of

TABLE IV

MAXIMUM, MINIMUM, AND AVERAGE ANNUAL TEMPERATURES FOR GRAND FORKS AND LARIMORE

Larimore				Grand Forks			
Year	Maximum	Minimum	Average Annual	Year	Maximum	Minimum	Average Annual
1914	95	–37	38.8				
1915	91	–37	38.9				
1916	93	–39	35.6				
1917	105	–38	34.9	1917	106	–36	34.6
1918	96	–35	39.1	1918	98	–35	38.9
1919	97	–36	37.6	1919	95	–36	37.0
1920	101	–30	39.0	1920	99	–32	38.5
1921	95	–25	40.05	1921	100	–25	40.7
1922	96	–36	39.3	1922	96	–36	39.9
1923	95	–35	39.1	1923	96	–31	40.0
1924	91	–35	37.2	1924	90	–33	36.9
1925	104	–32	39.1	1925	96	–32	39.0
1926	101	–26	38.8	1926	96	–26	39.0
1927	94	–27	37.8	1927	93	–28	38.3
1928	96	–24	40.1	1928	95	–22	40.6
1929	101	–33	36.5	1929	102	–32	37.2
1930	101	–36	40.0	1930	99	–33	40.7
1931	106	–19	43.3	1931	103	–15	44.2
1932	101	–26	38.9	1932	101	–24	39.7
1933	104	–33	40.1	1933	105	–37	39.8
1934	107	–31	41.9	1934	105	–29	41.0
1935	96	–31	38.1	1935	98	–35	38.1
1936	111	–41	37.6	1936	109	–42	36.8
1937	99	–34	37.8	1937	96	–36	37.0
1938	95	–28	41.6	1938	95	–29	40.04
1939	101	–35	41.8	1939	102	–38	40.02
1940	99	–24	40.2	1940	98	–25	39.4
1941	103	–29	41.8	1941	103	–31	40.8
1942	95	–25	40.5	1942	95	–28	40.5

any of these beds is an exposure of the Pierre which Upham[13] notes as outcropping on the North Branch of the Turtle River one and one half miles north of Niagara where the fossil **Baculites ovatus** Say was found in abundance.

[13] Upham, Warren: The Glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, p. 96, 1895.

Generalized Table of Geologic Formations for the Emerado Quadrangle

Cenozoic
- Pleistocene system
  - Eldoran series
    - Wisconsin stage
      - Mankato substage
        - Lake Agassiz silt, laminated clay and beach gravels
        - Glacial till

Mesozoic
- Cretaceous system
  - Upper Cretaceous series
    - Montana group
      - Pierre formation
    - Colorado group
      - Niobrara formation
      - Benton formation
      - Dakota formation

Paleozoic
- Silurian system
  - Stonewall formation
- Ordovician system
  - Stony Mountain—Red River formation
  - Winnipeg formation

Cryptozoic
- Granite

Pre-Glacial Geology

General Statement

The following brief descriptions of the beds presumed to underlie the glacial deposits of this area are given because of the interest they might have to anyone contemplating deep drilling. Because they are not exposed they are not given formal description.

Cryptozoic

Everywhere underlying the sedimentary rocks of the Paleozoic in eastern North Dakota is a grey or pink granite which is part of the Cryptozoic basement complex. This granite has been encountered in a number of wells in the Red River valley area and in some places it underlies the glacial drift directly indicating the absence of the intervening lower Paleozoic rocks.

Paleozoic

From the well log of the Grafton well [14] it appears that only 678 feet of lower Paleozoic sediments are present in that well.

Ordovician

The Ordovician consists of two formations, the Winnipeg and the Stony Mountain—Red River. In the Grafton well, the Winnipeg consists of 155 feet of dark red shale, green blue and grey shale. In Manitoba, the Winnipeg formation lies directly on the Pre-Cambrian. There "it consists of a basal sandstone containing thin, greenish shale partings. The shale becomes more abundant higher in the section, and grades into well bedded green shale which contains a middle Ordovician fauna. The basal sandstone varies in thickness, probably due to the irregularity of the floor upon which it was deposited".[15] The writers of the article referred to do not think that any Cambrian is present in the Grafton well but correlate what has been called Cambrian in that well by Kline [16] with the basal Winnipeg sandstone.

The Stony Mountain—Red River formation contains 537 feet of limestone and interbedded red shale. This formation of the Ordovician is fairly well exposed in quarries in the vicinity of Winnipeg, Manitoba. The limestone of the Stony Mountain—Red River is white, dense, and contains a fauna of very large individual **Receptaculites** and **Endoceras** as well as other large forms. In the Glenfield well,[17] the Richmond series of the Ordovician is represented as well as some older rocks classified as Pre-Richmond (?) Paleozoic.

Silurian

The Silurian is represented by the Stonewall formation which in the Grafton well is 138 feet thick. As this formation is directly overlain by drift, showing that erosion may have gone on for millions of years after deposition of the Stonewall, this thickness means little. The Stonewall consists of red and blue shale and white sandstone in the Grafton well.

In the Glenfield well, no rocks are correlated with the Silurian although 100 feet of light-colored limestone, grey shale and quartz sand overlie the known Ordovician rocks of Richmond age. These might be Silurian but with so little information such a conclusion is not justified.

Mesozoic

Only the rocks of the Upper Cretaceous are exposed in the state. Of the four formations listed only the Dakota is seen nowhere in North Dakota.

Colorado group

The lowest member of the Colorado group is the Dakota sandstone which, in its properly restricted sense according to Kline [18], consists of micaceous white sandstone with associated pyrite, gypsum and lignite. This is commonly the horizon of the "first flow" of the water well drillers. Commonly included with the Dakota is the immediately underlying Fuson shale and the Lakota sandstone. The Fuson is com-

[14] Laird, Wilson M., Selected Deep Well Records; North Dakota Geol. Survey vey Bull. 12, p. 28, 1941.

[15] Seager, O. A. et. al., Stratigraphy of North Dakota: Amer. Assoc. Petroleum Geologists Bull. vol. 26, p. 1422, 1942.
[16] Kline, V., Stratigraphy of North Dakota: Amer. Assoc. Petroleum Geologists Bull., vol. 26, p. 341, 1942.
[17] See Laird, op. cit. p. 20-21.
[18] op. cit. p. 351

monly spoken of as the "shale break" by the drillers. The Lakota consists of a white sandstone with a little shale and contains the "second" and "third flows". According to Seager **et al.**[19] the Fuson and Lakota are lower Cretaceous in age. It is not known whether they are present in the Emerado area or not.

Overlying the Dakota is the oldest formation exposed in the state, the Benton formation. The exposures are along the Pembina River in northeastern Cavalier County. It consists of dark grey to black shale containing large selenite crystals on weathered surfaces. About 150-180 feet of shale are poorly exposed along the Pembina River but Kline[20] reports that well logs show it to have an average thickness of 500-600 feet. Kline, on the basis of a study of well cuttings, divides the Benton into a " . . . lower, dark grey non-calcareous only slightly fossiliferous shale; a middle, light gray, highly fossiliferous limestone or calcareous shale; and an upper, dark gray, non-calcareous, only slightly fossiliferous shale." [21]

The youngest formation of the Colorado group is the Niobrara which in the nearest exposure, in the Pembina Mountains, consists of hard, grey, argillaceous limestone ("cement rock") and light-colored shales which are only slightly calcareous. In the Pembina Mountains, the Niobrara is 165 feet thick according to Kline. The fossils of the Niobrara dominantly consist of the microfossils belonging to the order Foraminifera.

Montana group

The lowest member of the Montana group and its only representative in this area is the Pierre shale. The Pierre is one of the most widespread geologic formations in North Dakota and would be exposed at the surface over most of eastern North Dakota were it not for the cover of glacial till. The Pierre consists of grey shales which weather into flat flakes and small slabs and pencil-like fragments. At the base of the Pierre is a peculiar banding of black and yellow beds of clay. Kline[22] called these yellow beds "fullers earth". She notes that they thin to the northwest but Barry and Melsted[23] note that they carry for as much as 300 miles northward into the Riding Mountains of Canada. The Pierre contains many individuals of certain cephalopods and pelecypods. Kline[24] reports the finding of a mososaur skeleton in the basal Pierre beds near Mountain, North Dakota. The Pierre is thinnest in the eastern part of North Dakota thickening westward to 2600 feet in the Kamp well.[25] Probably the Pierre in the eastern part of the state is from 500-1000 feet in thickness.

[19] **op. cit.** p. 1415.
[20] **op. cit.** pp. 351, 352.
[21] **op. cit.** p. 352.
[22] **op. cit.** p. 354.
[23] Barry, J. G. and Melstad, V. J., The Geology of Northeastern North Dakota with special reference to cement material: North Dakota Geological Survey Fifth Bienn. Report pp. 115-211, 1908.
[24] **op. cit.** p. 354.
[25] Laird, **op. cit.** p. 10.

Cenozoic

Name and definition

The term Cenozoic was apparently first used by Philips[26] in 1840. In present usage it covers all rocks laid down from the end of the Mesozoic to the present.

Pleistocene system

Name and definition

Charles Lyell[27] originally referred strata which contained more than 70% of recent species of shells to the newer Pleiocene or Pleistocene. This original definition included beds now regarded older than Pleistocene. The definition of the Pleistocene as now used includes all beds deposited during the Great Ice Age and contemporaneous marine, fluviatile, lacustrine, and volcanic beds. This is essentially the redefinition of the term Pleistocene as it was proposed by Forbes[28] and agreed to by Lyell.

Deposits belonging to the Recent are not included in the Pleistocene by the United States Geological Survey[29] although G. F. Kay and M. M. Leighton[30] include the Recent in the Pleistocene. Inasmuch as the withdrawal of the ice did not take place everywhere at the same time and as the line of demarkation between the Recent and Pleistocene deposits is difficult to draw in many areas, it seems logical to include the Recent as part of the Pleistocene period.

Eldoran series

Name and definition

The name Eldoran was proposed by G. F. Kay[31] to include the Wisconsin glacial, the Peorian interglacial, and the Iowan glacial stages of the Pleistocene epoch. As can be seen the original definition did not include the Recent but Kay and Leighton[32] later included the Recent in the Eldoran series making the classification for the Mississippi Valley as follows:

[26] Philips, J., Penny Cyclopaedia, vol. 17, pp. 153-154, 1840. Reference from Wilmarth, Grace, The geologic time classification of the United States Geological Survey compared with other classifications: U. S. Geol. Survey Bull. 769, p. 8, 1925.
[27] Lyell, C., Elements of Geology, French translation, appendix pp. 616-621, Paris, 1839. Reference from Wilmarth, Grace. **op. cit.** p. 47.
[28] Forbes, Edward, On the connexion between the distribution of the existing fauna and flora of the British Isles, and the geological changes which have affected their area, especially during the epoch of the Northern Drift: Great Britain Geol. Survey Mem., vol. 1, pp. 402-403, 1846. Reference from Wilmarth, **op. cit.** p. 48.
[29] See Wilmarth, Grace, Lexicon of geologic names of the United States: U. S. Geol. Survey Bull. 896, p. 1781, 1938.
[30] Kay, G. F. and Leighton, M. M., Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-674, 1933.
[31] Kay, G. F., Classification and duration of the Pleistocene period: Geol. Soc. America Bull., vol. 42, pp. 425-466, 1931.
[32] **op. cit.**

Pleistocene or Glacial period (system)
Eldoran epoch (series)
Recent age (stage)
Wisconsin age (stage)
Mankato substage (Late Wisconsin)
Cary substage (Middle Wisconsin)
Tazewell substage (Early Wisconsin)
Iowan substage

Wisconsin stage

Name and definition

This term was originally proposed by T. C. Chamberlin in the form of East Wisconsin stage of glaciation [33] because of the development in eastern Wisconsin. Later at the suggestion of Warren Upham, Chamberlin changed the name to Wisconsin and this name is still in use today although in a slightly expanded sense.

In 1931 M. M. Leighton [34] reclassified the Iowan and Wisconsin drifts and included in the Wisconsin, the Peorian loess and the Iowan drift. He also introduced several substage terms for the Wisconsin which he later [35] withdrew in favor of the classification listed above.

Mankato substage

Name and definition

This term for the latest Wisconsin substage was proposed by M. M. Leighton [36] and named for the excellent exposures in the vicinity of Mankato, Minnesota. In this report all the glacial till as well as the associated deposits of the Glacial Lake Agassiz will be considered to have been deposited during the last phases of the Mankato lobe of the Keewatin ice sheet.

Formation of Lake Agassiz

There appear to be two schools of thought in regard to the formation of Lake Agassiz. These two schools are supported by Upham and Leverett [37] on one hand and by Tyrrell and Johnston [38] on the other. Other references by these same authors could be noted but the ones listed give the best summaries. Briefly Upham and Leverett hold that Lake Agassiz began to form almost as soon as the ice front began to recede and that the recession was rapid enough so that the uppermost

[33] Chamberlain, T. C., in Geikie, James, Great ice age, 3rd ed. pp. 254-775, 1894.
[34] Leighton, M. M., The Peorian loess and the classification of the glacial drift sheets of the Mississippi Valley; Jour. Geol., vol. 39, pp. 45-53, 1931.
[35] Leighton, M. M., The naming of the subdivisions of the Wisconsin glacial age: Science, new ser., vol. 77, p. 168, 1933.
[36] op. cit. Science
[37] Upham, Warren, The Glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, p. 130, 1895.
Leverett, Frank, Quaternary geology of Minnesota and parts of adjacent states: U. S. Geol. Survey Prof. Paper 161, 149 pp., 1932.
[38] See Tyrrell, J. B., The Genesis of Lake Agassiz: Jour. Geol. vol. 4, pp. 811-815, 1896.
Johnston, W. A., The Genesis of Lake Agassiz: Jour. Geol. vol. 24, pp. 625-638, 1916.

series of beaches, the Herman beaches, were essentially contemporaneous throughout their entire extent.

Tyrrell and Johnston hold that Lake Agassiz did not begin to form until after the Mankato lobe had withdrawn a considerable distance into Manitoba. Finally, with the advance of the Laurentian glacier from the east and northeast, there was a juncture between it and the Keewatin glacier ponding the water forming Lake Agassiz. The water rose until it overflowed its first outlet by way of River Warren to the Minnesota River and thence to the Mississippi.

After the formation of the beaches above the Campbell beach, the lake was partially or wholly drained for Johnston notes the presence of an erosional disconformity between stratified clays of what he calls an earlier stage of Lake Agassiz and the clays of the later stage of Lake Agassiz below the level of the Campbell beach. The size and excellent development of the Campbell beach suggest to him that the lake remained at that level for a considerable time. "The great strength of this beach and the cutting down of the southern outlet of the lake to the level of the beach—which probably took place during the early stage of the lake—appear to show that it marks the upper limit of the second stage of the lake".[39]

As will be noted later in this report, a series of laminated or stratified clays is separated by an erosional disconformity from the true Lake Agassiz silts in the Emerado area. The relationship between this occurrence and that noted by Johnston in Canada is not entirely clear but it certainly is suggestive of two stages to the lake.

Description of Members

Till

The glacial till is the most widespread formation in this quadrangle. It not only outcrops over about two thirds of the map but it also probably underlies the rest of the area where it does not outcrop. The exposed surface of the till is almost always covered by a thin layer of wind-blown sand from less than 1 foot to 1½ feet in thickness. This sand is derived largely from the "delta" to the west as well as from the beach deposits which rest on the till.

The glacial till consists of blue clay containing pebbles of dense, white, crystalline limestone as well as pebbles of igneous and metamorphic rocks all of which came mainly from Canada. In certain places the till is so limy and light colored that it might almost be called a marl. In some places considerable quantities of Pierre shale fragments are present in the till. The Pierre shale probably underlies this area or the area a short distance to the west. In the one outcrop where Pierre shale fragments were so numerous (NE¼ Section 36, T. 152 N., R. 54 W. in Turtle River State Park) considerable quantities of gypsum crystals in the form of crack fillings and rosettes were found. Possibly much of this gypsum was derived from the Pierre shale

[39] Johnston, W. A., Winnipegosis and Upper Whitemouth River Areas, Manitoba Pleistocene and Recent Deposits: Can. Geol. Survey Mem. 128, p. 26, 1921.

fragments as that formation has been noted to contain much gypsum in other parts of the state.[40]

The pebbles in the till of this quadrangle are all rather small. Probably the majority are less than 1½" to 2" in diameter. Some few larger boulders are present but they are few compared to the great expanse of till exposed. On weathering, the surface of the blue clay oxidizes to a light tan color but the weathering has not gone far enough to notably affect many of the pebbles in the till. Occasionally a gneiss or schist pebble shows considerable weathering but it may be reasonably assumed that these pebbles may have been rather badly weathered before being picked up by the glacier.

Imbedded in the glacial till are occasional gravel lenses. These lenses are probably due to deposition by melt water running away from the ice. After the deposition of the gravel the ice then readvanced and deposited more till on top of them. These gravel lenses are important as ground water aquifers but often they have limited value due to the inability of the water to get into them because of the low permeability of the surrounding till.

The waves of Lake Agassiz had a modifying effect on the glacial till particularly between the Hillsboro and Emerado beaches. The vertical drop between these two is 30 feet and the horizontal distance between them is approximately two miles. Between these two beaches the till is quote notably reworked leaving the till sandier with less clay present. In fact, there is an area in the W½ of Section 12, T. 151 N., R. 53 W. just west of Emerado where the till is in reality a nicely washed sand and possibly should not be mapped as till. However, as the till in the vicinity of the northeast side of the Hillsboro beach is rather uniformly sandy this area was regarded as reworked till. No laminations in this reworked till were found. Where the beaches are closer together the till appears to be stonier and less reworked. This suggests either that the lake dropped faster in these places or that wave action was less severe.

The thickness of the drift in this quadrangle could not be determined with accuracy as no exposures of the lower boundary were seen. Simpson[41] reports that a well in the N½ Section 19, T. 149 N., R. 54 W. (somewhat south of this quadrangle) showed 82 feet of glacial drift. Wells nearer Grand Forks such as the one in the NW¼ Section 15, T. 151 N., R. 50 W.[42] showed at least 263 feet of lake sediments and till. It would on these bases be safe to assume that the till in the Emerado quadrangle was from 100 to 250+ feet in thickness.

The lower contact of the till with the underlying bedrock was not seen but it can safely be said to be in disconformable contact. The upper contact with both the delta and the beaches can also be regarded as disconformable as it is a surface of wave planation sloping eastward.

[40] Kline, V., Stratigraphy of North Dakota Amer. Assoc. Petroleum Geologists Bull., vol. 26, p. 354, 1942.
[41] Simpson, H. E., Geology and Ground-water Resources of North Dakota: U. S. Geol. Survey Water-Supply Paper, p. 138, 1929.
[42] Simpson, op. cit. p. 140.

The contact of the till with the laminated clay was not observed. However, there is a possibility that it might be transitional particularly if the laminated clay be regarded as being reworked till as Upham suggests.[43]

As noted previously, the glacial till was deposited as ground moraine between the Leaf Hills and Itasca Moraines.[44] Soon after its deposition its surface was modified by the waves of Lake Agassiz which occupied this area shortly after the ice front had receded northward. How long after the ice front receded before the waters of Lake Agassiz occupied this area is an unsettled question.

Laminated clay

The laminated clay occurs only in the northeastern corner of the quadrangle. The boundary of the clay on the southwest is not easily defined due to lack of exposures and to the fact that in many places the contact was drawn on the basis of auger holes which do not show the difference between till and laminated clay as well as in an exposure. These two members are not usually confused where vertical cross sections can be seen as the till is structureless and contains pebbles while the laminated clay is finely stratified.

The best exposures of the laminated clay are found along the banks of Kelly Slough. The most complete exposure of the clay is found in the SE¼ NE¼ Section 14, T. 152 N., R. 52 W. along the road just at the north edge of Kelly Slough where the road crosses the slough. The following section is exposed at this locality.

3.	Black sandy surface soil	1'+
2.	Lake Agassiz silt. Brown, slightly clayey	2'6"
1.	Laminated clay with few pebbles. Laminations are paper thin alternating between thicker dark-grey clay layers and thinner light-grey clay layers. Occasional iron-stained layers present. Exposed	16'

The dark clay layers when broken show a compact, massive structure that breaks with a conchoidal or shell-like fracture when broken across the bedding. When a block containing both light and dark layers is broken parallel to the laminations the split tends to occur along the lighter grey layers. These light grey layers might be just a little coarser grained causing the easier splitting along these surfaces.

In places where the clay has been fractured vertically at right angles to the lamination some of these crevices have been filled with iron-stained clay. Some of the crevices have also been filled with a whitish material probably gypsum as small gypsum crystals were noted in the bedding surfaces of the darker layers.

A good contact between the laminated clay and the underlying till was not observed anywhere in the quadrangle so no exact thickness can be given. At least 16 feet can be seen in the exposure afore

[43] Upham, Warren, The Glacial Lake Agassiz: U. S. Geol. Survey Mon. 25, p. 461, 1895.
[44] See Upham, op. cit. Plates XIX, XX.

mentioned. As it is known that the bottom of Kelly Slough is floored with glacial till, not more than 20 feet of laminated clay could be exposed here because the base of the above section is only about 4 feet above the water surface of the slough. Upham[45] mentions that this laminated clay in the neighborhood of Ojata is 10 to 15 feet thick.

The possible transitional nature of the contact between the laminated clay and the glacial till has already been noted. However, if an alternate explanation mentioned below of the laminated clay be accepted, then the contact might possibly be disconformable. The

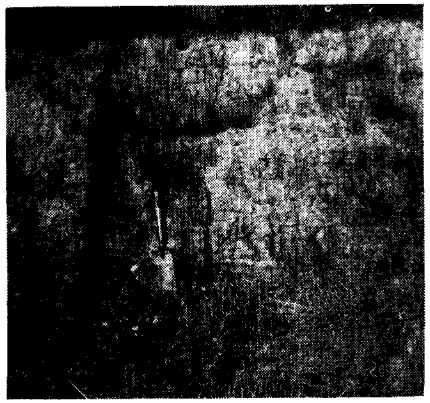

Fig. 3 Laminated clay exposure in the SE¼NE¼ Section 14, T. 152 N., R. 52 W.

contact between the laminated clay and the Lake Agassiz silt appears to be irregular and disconformable.

As has been noted, Upham suggests that this clay is "lacustrinely modified till which was englacial".[46] He also noted that the stratification is imperfect, a fact which does not appear to be substantiated by more recent work. See Figure 3. A more reasonable explanation, in view of the perfect almost varve-like lamination, would appear to be that these are definite lake sediments which may or may not be modified till. W. A. Johnston[47] has noted the presence in the Lake of the Woods region of what apparently are similar laminated clays intercalated with the glacial till of the same age as the underlying till of the Emerado quadrangle. Overlying these clays disconformably are the true Lake Agassiz silts so Johnston suggests that these laminated clays are the deposits of an early stage of Lake Agassiz which occupied this area prior to the time of a later stage of Lake Agassiz when the true silts were laid down.

[45] Upham, op. cit. p. 461.
[46] op. cit. p. 461
[47] Johnston, W. A., The Genesis of Lake Agassiz: Jour. Geol., vol. 24, pp. 625-638, 1916.

The paper-thin laminations definitely seem to indicate lake sediments which are not due to the reworking of the underlying till. It is difficult to visualize how such a succession of thin laminations could be produced by the reworking of the till. The author believes that these are definite lake sediments which may have been derived from the till elsewhere and carried here by streams, waves and currents but that they were not due to the reworking of the directly underlying till by the waters of Lake Agassiz. Whether these laminated clays are deposits of an earlier stage of Lake Agassiz is not entirely clear at present.

Silt

The silt has the smallest area of outcrop with the exception of the sand dunes and the terrace deposits of any of the members delimited on the map. It is found in the same general area as the laminated clay in the northeastern corner of the map but is not as extensive.

The silt is yellow-brown to brown in color. There is some clay with a little sand mixed with the silt but all the material is fine grained. No laminations in the silt are present and it is structureless as far as bedding features are concerned. It retains essentially the same color on weathering except the surface is usually blackened by the inclusion of partially decayed vegetable matter.

The silt is from 0 to 3 feet thick in this area and is more or less irregularly distributed. It increases in thickness to the northeast near the Red River. Upham[48] notes the presence of such silt or "lacustrine clayey sand" and notes that it was probably derived from the erosion of the escarpment to the west and spread with varying thickness on much of the surface eastward from the lower Ojata beach.

The silt is in disconformable contact with the underlying laminated clay.

The formation of the silts is still a controversial issue. Upham[49] believes that much of this silt is alluvium laid down after Lake Agassiz had drained away. He notes that it was deposited along old drainage channels and in irregularities in the old lake bed. He says this material contained shells, sedges, and even branches and logs of wood. None of these were seen by the author in the silts of the Emerado quadrangle. W. A. Johnston[50] regards this "alluvium" of Upham as the deposits of a later stage of Lake Agassiz. As far as can be seen in the Emerado area, the author tends to agree with the view of Johnston. The sorting of the sediment is almost too perfect to be due to stream action alone.

Delta

The so-called "delta" sediments are found only in the southwestern part of the map. The "delta" is an accumulation of material stretching from McCanna southward to Portland. Upham[51] says these "delta"

[48] op. cit. p. 461.
[49] Upham, op. cit. pp. 253-254.
[50] op. cit. p. 635.
[51] op. cit. p. 334.

sediments were derived partly from alluvium from stream erosion after the departure of the ice. Far larger quantities were derived, however, from what he calls "modified drift" or what Leverett calls outwash.[52]

Upham says that the "delta" sediments show stratified sand and fine silt. Most of the exposures seen by the writer showed little stratification. The sand and silt is light tan to brown and grey in color but contains considerable quantities of organic material at the surface giving a rich black soil. Much of the sand has been derived from the erosion of the underlying Pierre shale.

In the Emerado quadrangle, no outcrop occurs where the thickness of the "delta" sediments can be measured. Upham says its thickness at Larimore is 60 feet with an average thickness over its entire extent of 30 to 40 feet. In this quadrangle the delta "front" makes a rather abrupt rise above the till to the north and east of about 20 to 30 feet. If the till surface beneath the "delta" is nearly flat, a thickness of 30 feet for the "delta" sediments in this area would probably be approximately correct.

The contact of the "delta" with the till has already been described as a disconformable contact.

As has been noted Upham describes this as "modified drift" or outwash deposited in Lake Agassiz in the form of a delta. Leverett feels that they are more in the nature of outwash without being deposited in the lake. In any event, the lake did cover the "delta" after its formation for the Herman, Norcross, and Tintah beaches cross it. The material is very well sorted, much better sorted than most outwash so possibly it is true outwash that was further sorted by later lacustrine action. Or, it might originally have been a very well-sorted outwash.

Beach gravels

The most prominent ridges of beach gravel run in a northwest-southeast direction across the center of the map. There are five major sets of beach ridges which contain considerable quantities of gravel. These are, starting from the southwest and going toward the northeast, the Campbell, McCauleyville, Blanchard, Hillsboro and the Emerado. Northeast of the Emerado beach is the Ojata beach which is not distinct and contains little gravel. It is noted mainly by the presence of a low wave cut cliff. Southwest of the Campbell beach and approximately parallel with the edge of the "delta" is the Tintah beach which contains little or no gravel in this quadrangle but does have a fairly distinct wave cut cliff.

The beach gravels are lenticular masses of gravel from 100 feet or less in width up to as much as one-quarter to one-half mile trending in about N. 45° W. direction in this quadrangle. Some of the beaches are multiple, the several beach ridges not varying more than

[52] Leverett, Frank, The Quaternary geology of Minnesota and adjacent states: U. S. Geol. Survey Prof. Paper 161 pp. 126-127, 1932.

2 or 3 feet from the general level of the whole beach. In the W½ Sections 29 and 32, T. 150 N., R. 52 W., the Campbell and McCauleyville beaches have united forming a series of low, undulating gravel ridges over one-half mile in width. Other beaches, particularly the Emerado, tend to be single but are not continuous. In the Emerado beach, the ends of the discontinuous parts tend to arrange themselves in an **en echelon** fashion (the end of one length of beach overlapping the end of another).

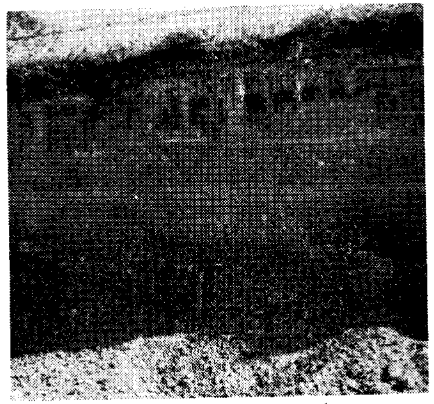

Fig. 4 Gravels found in gravel pit in the SW¼ Section 36, T. 152 N., R. 54 W. in Turtle River State Park. Note cross bedding and size of gravel.

The gravels of the beaches are fairly well sorted (See Fig. 2 for mechanical analysis p. 9). The gravels are crudely stratified with different sized pebbles in each layer. Cross bedding is common but no definite current direction could be determined as might be expected in a deposit which is a combination of wave and current action.

The thickness of the gravels was not easy to determine due to the fact that seldom is there a complete exposure from top of the beach to the underlying glacial till. The beach gravels in some places such as the gravel pits along Route 2 in the Campbell beach in the NW¼ Section 6, T. 151, N., R. 53 W. are more than 12 to 15 feet thick. In some of the Ojata beaches, as well as others, the gravel may be less than 2 feet in thickness or be absent altogether. An average thickness of approximately 10 feet would probably be nearest the facts.

The beach gravels are in disconformable relationship with the underlying glacial till. As has been noted elsewhere (p. 20) this contact is a surface of wave planation which slopes gradually northeastward. This fact and the fact that the beaches are thicker on the northeast side have an important effect on the ground water in the beaches.

The beach series which were noted in this quadrangle and their general elevations as taken from the topographic map are as follows:

Tintah	1050	Hillsboro	930
Campbell	1000	Emerado	900
McCauleyville	980	Ojata	870-880
Blanchard	950-960		

These elevations differ in certain respects from those given by Upham.[53]

The Tintah beach was named by Upham[54] from Tintah in Traverse County, Minnesota. The elevations he gives for the Tintah beaches (**a** and **b**) in the latitude of Grand Forks are, **a** 1065 feet, **b** 1045. Apparently only the **b** beach is represented in this quadrangle. Little or no gravel was found on this beach, with only the beach form of the reworked deltaic material being found.

The Campbell beach series was named by Upham[55] for the town of Campbell in Wilkin County, Minnesota. The elevations he gives for the Campbell beaches (**a, aa, b**) are **a** 1015 feet, **aa** 1010 feet, **b** 1000 feet. In the Emerado quadrangle apparently only the **b** beach is distinguishable. However, the **aa** beach has been mapped in the Turtle River State Park just west of this quadrangle.[56] The Campbell is represented by a gravel ridge everywhere in the quadrangle except in Sections 17, 20 and 21, T. 151 N., R. 53 W. where it is present as a low wave cut cliff with no gravel.

The McCauleyville beach series was named by Upham[57] for the town of McCauleyville in Wilkin County, Minnesota. Upham gives the elevations of the McCauleyville beaches as **a** 987 feet, **aa** 981 feet, and **b** 975 feet in the latitude of Grand Forks. In the Emerado area, however, only the **aa** and **b** beaches could be distinguished with the level of the beaches being generally found about 980 feet A. T. Both the McCauleyville and the Campbell beaches decrease in massiveness and width from the southeast to the northeast in the Emerado quadrangle. The exact reason for this is not known, but probably the tilting of the lake bottom had something to do with it.

The Blanchard beaches were named by Upham[58] for the town of Blanchard in Traill County, North Dakota. He notes that there are three Blanchard beaches in the latitude of Grand Forks, **a** 960 feet, **b** 948 feet, and **c** 935 feet. As far as could be seen in this study there are only two Blanchard beaches at 960 feet A. T. and 950 feet A. T. The beach which Upham gives at 935 feet A. T. as his Blanchard **c** beach appears to be more closely related to the Hillsboro beach. The Blanchard beach is widest and most massive in the southern part of the quadrangle becoming narrower and splitting into a number of smaller

[53] op. cit. p. 476
[54] op. cit. p. 397.
[55] op. cit. p. 408.
[56] See Laird, Wilson M., The geology of the Turtle River State Park: North Dakota Hist. Society Quat. Jour., vol. 10, pp. 245-261, 1943. Reissued as Bull. 16 of the North Dakota Geol. Survey.
[57] op. cit. p. 428.
[58] op. cit. p. 445.

beaches in the northern part. The Blanchard beaches are very distinct topographic features standing 5 to 10 feet above the surrounding plain.

The Hillsboro beach, named by Upham[59] for Hillsboro, Traill County, North Dakota, has an elevation of 923 feet A. T. in the latitude of Grand Forks according to Upham. The present topographic map shows the correct elevation to be 930 feet A. T. The Hillsboro beach is often double and sometimes triple but the general elevation of 930 feet holds for all beaches designated as belonging to this stage. The

Fig. 5. Beach ridge formed by McCauleyville beach in the NE¼ Section 6, T. 151 N., R. 53 W. Picture taken from the northeast or lake side of the beach. Note the vegetation on the beach indicating the presence of shallow ground water.

Hillsboro beach is not as distinct a topographic feature as either the Blanchard or Emerado beaches.

The Emerado beach named by Upham[60] for Emerado, Grand Forks County, North Dakota, has an elevation of 890 feet for the **a** beach and 885 feet for the **b** beach. In this quadrangle only one beach could be clearly designated as the Emerado beach and its elevation was uniformly 900 feet A. T. It is a particularly distinct ridge in the vicinity of Emerado where it stands at least 8 to 10 feet above the surrounding plain.

The Ojata beach series, named by Upham[61] for the former town of Ojata, Grand Forks County, North Dakota, has elevations of 875 feet A. T. for the **a** beach and 865 feet A. T. for the **b** beach. During this study, the elevations of these beaches were found to be more nearly 880 feet A. T. for the **a** beach and 870 for the **b** beach. During this study, the elevations of these beaches were found to be more

[59] op. cit. p. 451
[60] op. cit. p. 456
[61] op. cit. p. 460.

nearly 880 feet A. T. for the **a** beach and 870 for the **b** beach. These beaches are poorly developed in this quadrangle as far as gravel is concerned but low wave cut cliffs are found where the gravel is absent.

The Tintah, Campbell, and McCauleyville beaches were developed with Lake Agassiz draining southward according to Upham although more recent work by Leverett has shown that probably the McCauleyville beach was built when the lake drained to the northeastward.[62] On the basis of the most recent information it would appear that the McCauleyville, Blanchard, Hillsboro, Emerado, and Ojata as well as other lower beaches not within the boundaries of this quadrangle were formed as the lake drained to the northeastward.

Upham[63] ascribed the succession of beaches from the Herman through the McCauleyville, including the Tintah and Campbell to successive uplifts of the land adjoining the outlet of Lake Agassiz at the River Warren. That is, the beaches were formed during periods of quiescence when River Warren was nearly graded, downcutting its chanel very little. It also has been noted that the various beaches not only rise to the northward but also split into several beaches. For example, the Herman beach which is the highest of the Lake Agassiz beaches (but not found within the confines of this quadrangle) at the south end of the lake is one beach while at the north end it is composed of seven beaches.[64] This bifurcation is due, according to Upham, to differential uplift through release of weight on the earth's crust after the great ice sheet melted. The inclination of the beaches due to this uplift amounts to about one foot per mile from the south end of the lake for 300 miles northward.[65] Most of this tilting took place prior to the formation of the Campbell beach, but farther north in Canada tilting again occurred after the formation of these beaches.

Recent Stage

Name and definition

Charles Lyell[66] apparently first used the term Recent for rocks deposited more or less during the time of man's occupancy of the earth. More recently Kay and Leighton[67] have regarded the Recent as part of the Pleistocene and it is thus regarded in this report.

Sand dunes

Sand dunes are not particularly common in this quadrangle although wind-blown material is. The most prominent dunes are those situated on the "delta" in the southwestern corner of the quadrangle in the SE¼NE¼ Section 20, T. 150 N., R. 53 W. Some doubtful mounds, possibly old fixed dunes, are located in the center of Section 9, T. 151 N., R. 52 W.

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62 Letter from Dr. Frank Leverett dated August 1, 1943.
63 op. cit. p. 225.
64 Upham, op. cit. p. 475-476.
65 Upham, op. cit. p. 267.
66 Lyell, Charles, Principles of Geology, vol. 3, pp. 52-53, 1833. Reference from Wilmarth, Grace, U. S. Geol. Survey Bull. 769, pp. 46-47, 1925.
67 Kay, G. F., Leighton, M. M., Eldoran epoch of the Pleistocene period: Geol. Soc. America Bull., vol. 44, pp. 669-674, 1933.

The material composing the dunes is fine sand and silt. The dunes are for the most part less than 10 feet above the surrounding surface.

Terrace deposits

The terrace deposits are found only along the Turtle River in the northwestern corner of the map. The deposits consist mainly of fine silt which toward the bottom become coarser sand and fine gravel. The color of the silt is light tan to grey weathering to a brown.

The thickness of the terrace deposits varies from 10 to 20 feet but the bottom contact is seldom seen. In a new stream cut in Turtle River State Park in the SW¼ Section 36, T. 152 N., R. 54 W. the base of the terrace deposits is exposed about 13 feet below the top of the terrace. The contact between the deposits and the underlying till is sharp indicating that the terrace deposits are lying on a cut terrace formed when the stream was flowing at that elevation.

The presence of a cut terrace beneath the terrace deposits and the fact that the stream is now cutting below the top of the cut terrace as well as the coarseness of the bottom layers of the terrace deposits are facts from which some very interesting speculations may be drawn. The cut terrace clearly indicates that the stream was cutting at that level. Then after cutting was less dominant the coarser materials began to be deposited. As time went on either the water was less abundant or the stream was overloaded so that much material was deposited on top of the coarser sediments. Finally the immediate base level of the stream dropped and the present stream not only cut through its former deposits (now left as terraces) but into the former cut terrace. The exact correlation of all these events with other events in the Lake Agassiz basin cannot be made until more regional field work has been done.

GROUND WATER RESOURCES

General Statement

Occurrence of Ground Water

When we speak of ground water we mean that water which occurs in the pore spaces of the consolidated and unconsolidated materials below the surface of the earth. Rocks near the surface of the earth, while they may appear solid, contain innumerable small pores and crevices. Water that fills these intersticies is spoken of as ground water and may be made available or even released at the surface by means of wells.

It can be said definitely that most underground water originates as rainfall or some other form of precipitation. Part of the water falling to the earth's surface as rain sinks into the ground and slowly percolates downward but some collects at the surface as rivers and lakes. These surface waters may eventually recharge the underground water supply.

The amount of space in a given volume of rock which is taken up by pore spaces and small crevices and cavities is spoken of as **porosity** which is expressed in terms of percentage. For example, if we have a cubic foot of sandstone which has a porosity of 15% it means that 15% of that cubic foot of rock consists of open spaces. If the pore spaces of this rock are entirely filled with water the rock is said to be saturated with water.

According to Meinzer,[68] "The porosity of a sedimentary deposit depends chiefly on (1) the shape and arrangement of its constituent particles, (2) the degree of assortment of its particles, (3) the cementation and compacting to which it has been subjected since its deposition, (4) the removal of mineral matter through solution by percolating waters, and (5) the fracturing of the rock, resulting in joints and other openings."

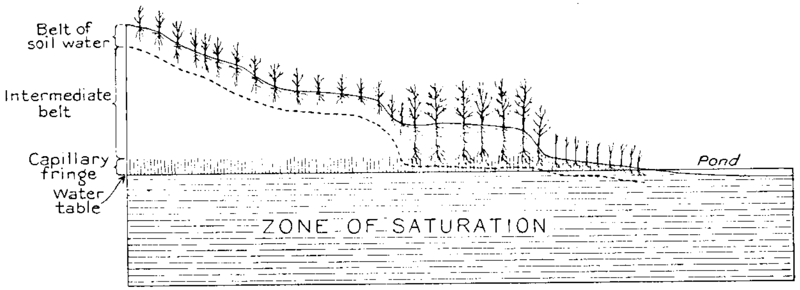


Fig. 6. Diagram of the occurrence of shallow ground water. Figure taken from U. S. Geol. Survey Water-Supply Paper 489, p. 82, 1923. and lent through the courtesy of Dr. O. E. Meinzer.

A rock may be porous and hold water but unless it will give that water up readily when a well is drilled into it, the rock has little value as a water-bearing formation. The capacity of a rock to transmit water under pressure is regarded as its **permeability.** Detailed studies made by the United States Geological Survey on permeability show that by rigid measurement and calculations the permeability of water-bearing horizons can be determined with mathematical exactness.

Shallow Water

Below a certain level beneath the earth's surface the permeable rocks are generally filled with water. This zone of water-saturated rock is spoken of as the zone of saturation. The upper surface of this zone is called the water table. (See Figure 6). There may be several saturated zones separated by impermeable layers and if so the area in question may have more than one water table.

Above the water table is a capillary fringe by which small amounts of water are drawn upward from the water table. The limit to which water may be drawn upward depends on the size of the grains composing the rock and the time allowed for capillary action to operate.

Above the capillary fringe is the intermediate belt which contains

[68] Meinzer, O. E., The occurrence of ground water in the United States: U. S. Geol. Survey Water-Supply Paper 489, p. 3, 1923.

little water. What water is present in this zone is in transit downward to be added to the zone of saturation.

The belt of soil water is the zone immediately underlying the land surface. This belt is the one in which the plants grow and get most of their water unless they are near the water table, (See Figure 6) or have very long tap roots. The thickness of the belt of soil water varies but it is usually only a few feet thick. Most of the water which escapes downward from the belt of soil water will eventually become part of the zone of saturation.

The amount of water escaping downward from the belt of soil water depends on what time of year the precipitation is greatest and the amount of plant growth as well as the size of the particles making up the soil. If the greatest precipitation came during the months when the ground was frozen little water would sink into the ground and most would run off. In North Dakota the largest amounts of precipitation come during the months of May, June, and July (See Table II) which are also the main growing months for crops. It is a well-known fact that plants transpire a tremendous amount of water vapor into the air which comes from moisture in the soil. Therefore, it is suggested that relatively little of our precipitation becomes part of the underground water storage due to large transpiration loss from plants whose roots are primarily in the belt of soil water.

Artesian Water

An artesian well is defined as a well in which the water rises in the well above the formation in which the water was encountered. Some artesian wells flow above the land surface while others do not. The necessary conditions for an artesian well are (1) a hydrostatic head to force the water above the water-bearing horizon, (2) a water-bearing horizon which will allow the water to pass readily through it, (3) beds above and below the water-bearing horizon which will not allow the water to escape naturally.

The hydrostatic head is usually supplied by an inclination of the beds. In the Red River valley area the hydrostatic head is supplied by inclination to the northeast of the shallower water-bearing horizons and the very slight eastward or northeastward dip of the Dakota sandstone or the deeper water-bearing sand. The regional dip of the Dakota sandstone in the State is to the west, however, for at Glenfield in Foster County the Dakota sandstone is 50 feet above sea level, near Steele in Kidder County 524 feet below sea level, and in the deep well near Ray in Williams County 2247 feet below sea level. The eastward dip in the Emerado quadrangle is apparently only a minor reversal of dip.

It may be rightfully asked where the water in the artesian acquifers comes from. For the shallow gravel lenses in the glacial till the source of water is largely the water which over a period of thousands of years percolated very slowly through the glacial till overlying these lenses. It is possible that some of the water may have been in the gravel from the time it was laid down when the front of the glacial ice stood near this area and was being rapidly melted.

The source of the water in the deeper Dakota sandstone is more of a problem. The traditional explanation is that the water entered this formation along the front of either the Rocky Mountains or the Black Hills where it is exposed at the surface and traveled through the sandstone as far the sandstone extended. Another explanation might be that the water was squeezed out of the overlying Benton, Niobrara, and Pierre shales by compaction and thus was forced into the more porous and permeable Dakota sandstone.

Description of the Occurrence of Ground Water In the Emerado Quadrangle

Shallow Water

As can be seen by reference to Plate III it will be seen that the major area having shallow wells is in the southwestern corner of the map. Plate II, the geologic map, shows that this area is also the area of the delta or fine-grained outwash. It will be noted by reference to Table V that the depth of the wells over much of Pleasant View township is from 5 to 15 feet with an average well depth of 10 to 18 feet.

Shallow water under free water table conditions is also found in the central part of the area that is traversed by the beaches of old Lake Agassiz. The water table in these beaches averages from 6 to 15 feet below surface with the water-bearing formation generally being the beach gravels. Wells on the east side of the beaches are, in general, more adequate than those on the west side. The reason for this condition can be found in considering the geology of the area. As has been discussed in another section of this report (p. 20) the surfaces of the till beneath the beaches is one of wave planation and slopes gently eastward. The gravels readily admit water which filters down to the bottom of the gravel lense and then moves eastward along the upper surface of the glacial till which is quite impermeable to water. Then, too, the gravels are often thicker on the eastern side of the beach giving a greater thickness of water bearing formation in which that water can accumulate.

The till areas between the various beaches are not very favorable for shallow water supplies. This is largely due to the low permeability of the glacial till which is exposed at the surface in these areas.

In the northeastern corner of the quadrangle few wells have been developed that show ground water under free water table conditions. Several of the shallow wells there, some of which are 35 feet or less in depth, flow and nearly all shallow wells show artesian pressure.

Artesian Water

Plate III shows that much of the area of this quadrangle contains artesian wells. It will be noted that, in general, there are two major areas, one where the wells are flowing and the other where the wells are artesian but not flowing. It was also found that the artesian wells

TABLE V

DEPTHS OF SHALLOW WELLS IN THE EMERADO QUADRANGLE †

NAME OF TOWNSHIP	NUMBER OF WELLS AT VARIOUS DEPTHS									
DEPTHS	10–	10+	20+	30+	40+	50+	60+	70+	80+	TOTALS
Mekinock		7	3	5	4	2	3			24
Blooming		5								5
Chester		9	3	1	1					14
Oakville		4	6		1					11
Pleasant View	5	25	10	2	1					43
Fairfield		11	2	1	1	1			1	17
Part of Washington		5	1	1						7
Part of Union	2	2								4
TOTAL	7	68	25	10	8	3	3		1	125

† This table includes only the wells for which adequate data is available.

TABLE VI

DEPTHS OF ARTESIAN WELLS IN THE EMERADO QUADRANGLE ‡

NAME OF TOWNSHIP	NUMBER OF WELLS AT VARIOUS DEPTHS					
DEPTHS	100–	100+	200+	300+	400+	TOTALS
Mekinock (non-flowing)	5	3		1		9
Blooming (flowing)	4	8	5			17
Blooming (non-flowing)	1	1				2
Chester (non-flowing)	2	12	1	2	1	18
Oakville (flowing)	4	2	2			8
Oakville (non-flowing)		8	4			12
Pleasant View (non-flowing)		4	1	1		6
Fairfield (non-flowing)	1	11	1		1	14
Part of Washington (non-flowing)		2				2
Part of Union (non-flowing)	1	2	1			4
TOTALS	18	53	15	4	2	92

‡ This table does not include all the artesian wells in the quadrangle because adequate data as to depths of wells, depths to water, etc., were not available or the information was regarded as inadequate.

produce from various depths. Some go as deep as the Dakota sandstone while others are much shallower.

This area is within the boundaries of the region mapped by Simpson[69] as the Red River valley area where ". . . either glacial drift or Dakota sandstone or both will probably yield flowing wells with light to moderate pressure. The depth ranges from 150 to 500 feet." Simpson[70] visualizes the geologic conditions in the area as a trough-shaped basin in which the glacial material has been deposited. As the trough declines to the northward the glacial material not only declines toward the axis of the trough but also to the northward. There is thus a northeastward dip of these beds. This condition according to Simpson

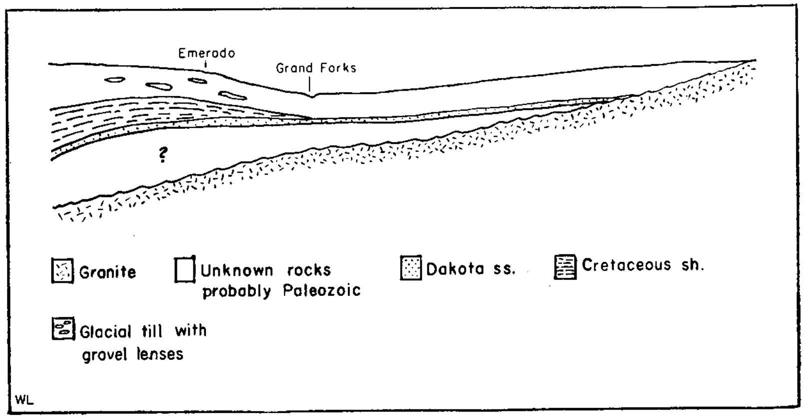


Fig. 7. Diagrammatic geologic cross section of the Red River Valley in the latitude of Grand Forks.

gives rise to the hydrostatic pressure which causes flowing and non-flowing artesian wells in this quadrangle as far as the shallower glacially-deposited gravel lenses are concerned. (See Figure 7). The source of the Dakota sandstone water has already been noted. There is a possibility that part of the water in the Dakota sandstone may have entered on the east side of the Red River valley where it laps up on the Pre-Cambrian granite. It would seem, however, that recharge from this direction would be slight due to the opposing pressure of the water flowing out of the Dakota.

In plotting the data relative to the artesian wells in this quadrangle it was noted that regardless of the water-bearing horizon from which the water came, no wells flowed above the 890 foot contour line. This suggests strongly that there is some connection between the Dakota sandstone aquifer and the shallower gravel lenses in the glacial till. It is unfortunate that so little reliable information on the subsurface geology is available. Most of the water-well drillers either

[69] Simpson, H. E., Geology and ground water resources of North Dakota: U. S. Geol. Survey Water-Supply Paper 598, Plate I, 1929.
[70] op. cit. p. 49.

do not keep adequate well logs or they use the jetting type rig which makes it impossible to get any accurate idea of where the drill penetrates the different types of strata.

If it were assumed that the glacial drift everywhere in the Emerado quadrangle averaged 200 feet in thickness, the thickness of the shale above the Dakota sandstone would average from 200 feet in the western part of the quadrangle to 20 feet in the eastern part.[71] It was found that none of the artesian wells in this area were in the suggested limits of the shale but that all were either in the Dakota sandstone or in the 200 feet allotted to the glacial till. This is what might be expected as neither the Pierre nor the immediately underlying shales produce any extensive quantities of water anywhere in the State.

It would seem that inasmuch as the Dakota sandstone appears to be overlaid with both the Benton, Niobrara and Pierre group and the glacial till (both of which are usually thought of as most impermeable) it would seem that the water of the Dakota sandstone would be successfully held in its place. However, this does not appear to be the case. As has been mentioned before, none of the artesian wells flow above 890 feet, a fact which strongly suggests some connection between aquifers. It is true that where the artesian wells are most abundant and where they flow is in that area where the shales overlying the sandstone are undoubtedly the thinnest (probably less than 60 feet).

Inasmuch as this area was considerably eroded prior to glaciation, it would not be impossible that in places the shale would have been entirely eroded exposing the Dakota sandstone. Then as the glacier came and deposited the till directly on the sandstone, the water under pressure could permeate directly into the overlying till. Areas where there was little or no shale cover would thus be areas of excessive leakage from the Dakota sandstone. In time, this leakage would be reflected on the surface by swampy, alkali-saturated ground. Such an area as Kelly Slough and the associated alkali spots in the northeastern part of the quadrangle is strongly suggestive of such a zone of leakage.

Cost of Wells

The cost of a well depends largely on the depth to which a well must be dug or drilled and the size of the casing. In the southwestern corner of the quadrangle and on the beaches where it is only 10 to 15 feet to water, the wells cost from $25 to $50 each depending on the way they are constructed. The deeper artesians, as might be expected, are more costly. In the eastern part of the quadrangle where it is not necessary to go deeper than 250 to 260 feet to reach the Dakota sandstone the cost is around $250 to $300. However, in the western part of the Emerado area the cost of a well going to the Dakota is usually $500 to $700.

[71] The figure of 200 feet is not entirely arbitrarily chosen for the log of the Bridgeman-Russell creamery well in Grand Forks shows 210 feet of glacial till and 15 feet of blue shale overlying the Dakota sandstone.

SKETCH MAP SHOWING THE OCCURRENCE OF GROUND WATER IN THE EMERADO QUADRANGLE

NORTH DAKOTA GEOLOGICAL SURVEY

PLATE III — Bulletin 17

LEGEND

Mainly flowing wells
35-265 feet deep

Non-flowing artesians
88-435 feet deep
Shallow wells
7-50 feet deep

Mainly shallow wells
10-20 feet deep

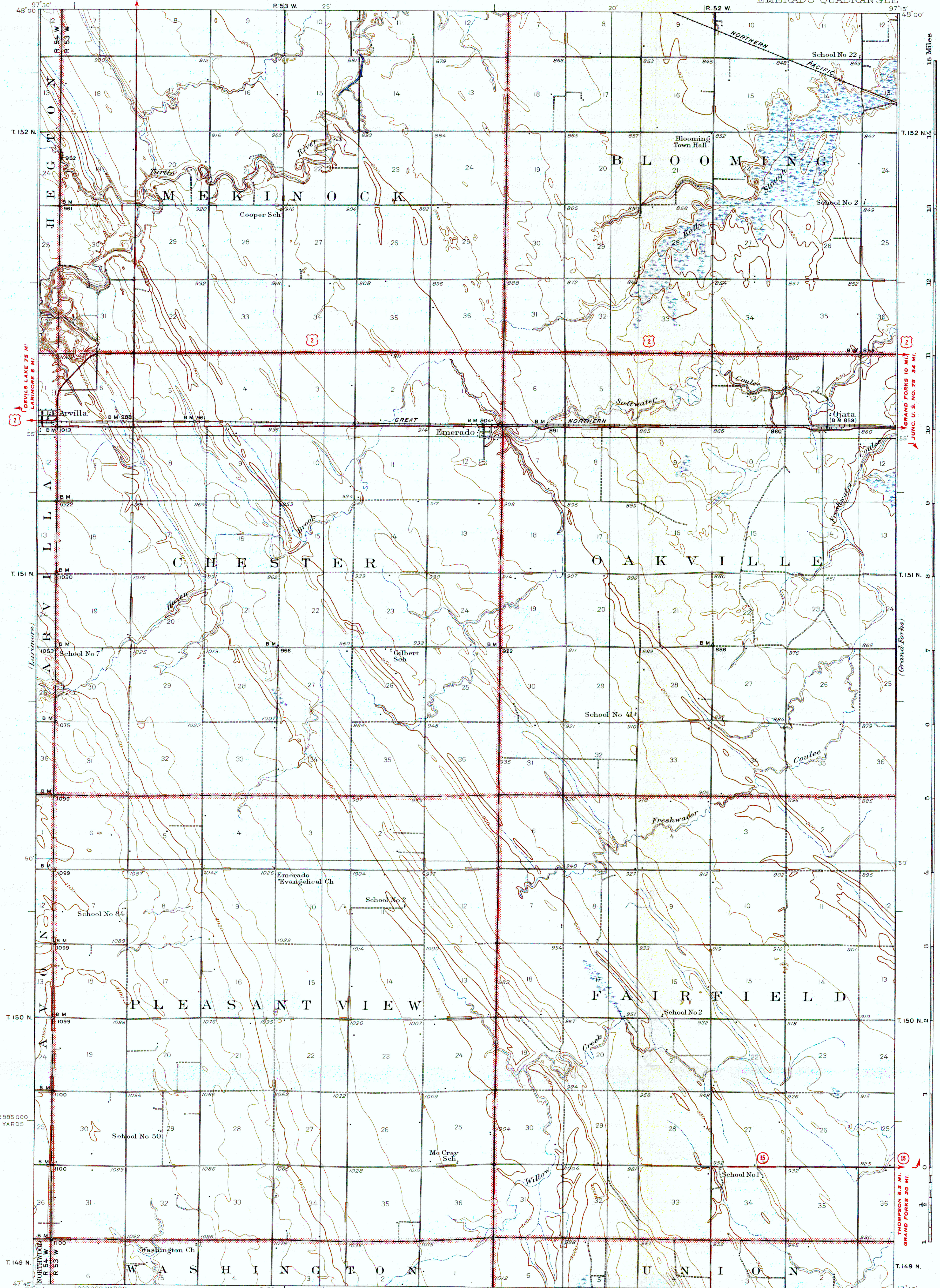
PLATE I — Bulletin 17

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

GILBY (JUNC. STATE NO. 33) 5.5 MI.
HONEYFORD 2.5 MI.

NORTH DAKOTA GEOLOGICAL SURVEY

NORTH DAKOTA
(GRAND FORKS COUNTY)
EMERADO QUADRANGLE



Topography by Daniel Kennedy, E. J. Fennell, L. V. Johnson, R. W. Blackburn, C. E. Harding Jr. and C. T. Galloway
Surveyed in 1934

Polyconic projection. 1927 North American datum
5000 yard grid based upon U.S. zone system, D

Scale $\frac{1}{62500}$

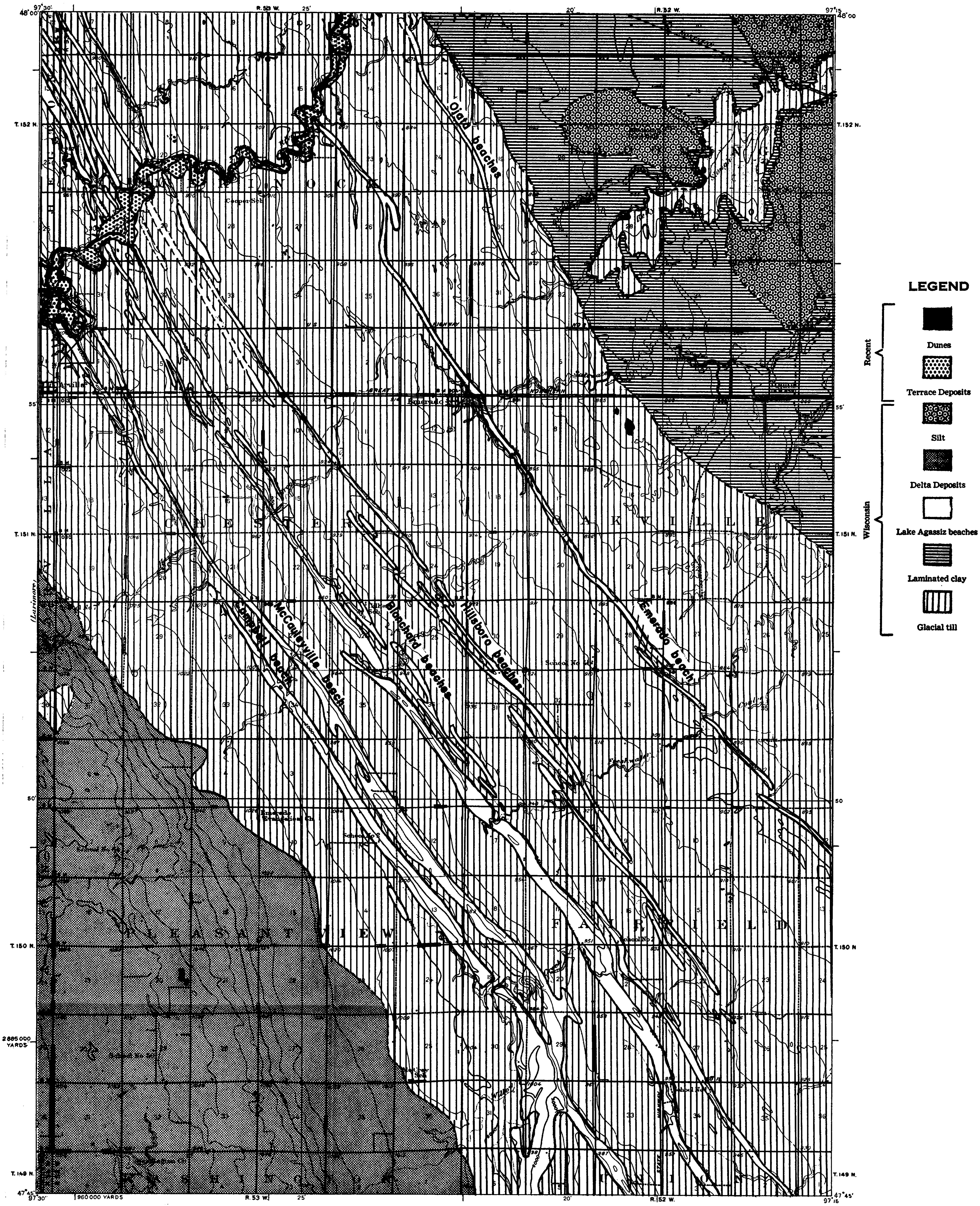
4 Miles
20000 Feet
5 Kilometers

APPROXIMATE MEAN DECLINATION, 1934

Contour interval 10 feet
Datum is mean sea level

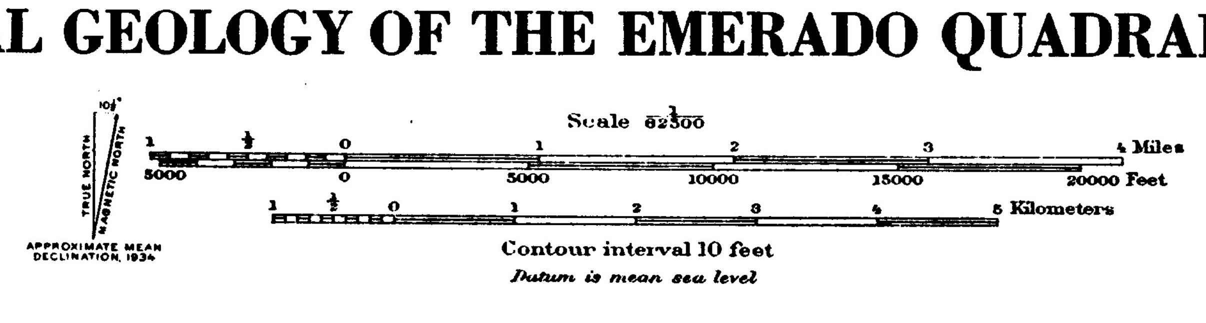
ROUTES USUALLY TRAVELED
HARD IMPERVIOUS SURFACES
OTHER SURFACE IMPROVEMENTS
1943
U. S. ROUTE
STATE ROUTE

EMERADO, N. DAK.
Edition of 1936
reprinted 1943
N4745-W9715/15



AREAL GEOLOGY OF THE EMERADO QUADRANGLE

Topographic base surveyed by U. S. Geological Survey, 1934



Geology by W. M. Laird
J. S. Templeton, 1941-43