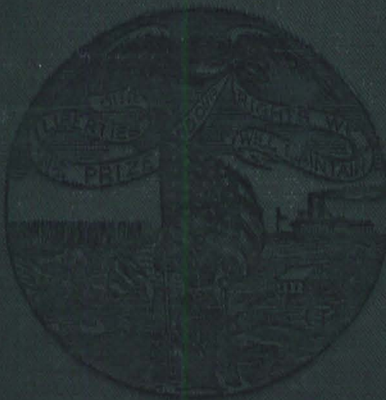
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IOWA

GEOLOGICAL SURVEY

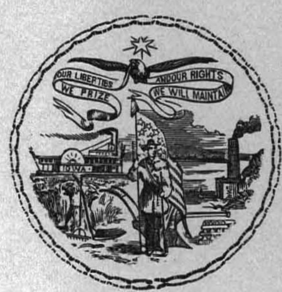
VOLUME XXVI

ANNUAL REPORT, 1915

WITH

ACCOMPANYING PAPERS

GEORGE F. KAY, Ph. D., State Geologist
JAMES H. LEES, Ph. D., Assistant State Geologist



DES MOINES
Published for Iowa Geological Survey

Published by
THE STATE OF IOWA
Des Moines

ROBERT HENDERSON, STATE PRINTER
J. M. JAMIESON, STATE BINDER
1917

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TWENTY-FOURTH ANNUAL

Report of the State Geologist

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1915.

To Governor George W. Clarke and Members of the Geological Board:

GENTLEMEN: The Iowa Geological Survey has carried forward successfully the plans that were approved by the Board at the beginning of the field season of 1915. As in former years, several well-trained instructors and advanced students connected with educational institutions were secured to conduct investigations. These persons have been in the employ of the Survey only during the summer months, when the chief field work of the Survey is done. This policy has enabled the Survey, with a modest appropriation, to accomplish much more, proportionately, than could have been accomplished by other methods with a considerably larger appropriation.

The State Geologist directed the work of the Survey and made some detailed studies of the glacial deposits of the state, especially in southern Iowa and in parts of western Iowa. As a result of these studies a paper entitled "Some features of the Kansan drift in southern Iowa" was published in the Bulletin of the Geological Society of America, Volume 27, pages 115 to 117; and in Volume XXVI of the Reports of the Iowa Geological Survey is a paper entitled "Pleistocene deposits between Manilla in Crawford county and Coon Rapids in Carroll county, Iowa". In these papers some new interpretations of important phases of the glacial and interglacial deposits of Iowa are presented, interpretations which give promise of having considerable significance in solving the complex history of the Pleistocene period. Some of the investigations require detailed studies to be made of the chemical compositions of glacial materials, and it is gratifying to be able to state that Dr. J. N. Pearce of the Chemistry department of the University of Iowa has undertaken to do this work.

During the field season of 1915, Dr. James H. Lees, the Assistant State Geologist, did special work in several of the counties of the state, particularly in Crawford and Greene counties. When Doctor Lees is not engaged in field work, his time is occupied in editing the reports of the Survey and in furnishing information regarding the resources of the state to those who come to the office or who seek information by correspondence. During the past few years Doctor Lees has performed an important service to the state in connection with an exhibit of some of the mineral resources of Iowa at the State Fair. The State Fair is visited each year by thousands of the citizens of Iowa, and the Survey has felt that there is no more opportune way of having them become acquainted with the resources of the state than by means of an exhibit. To those who visit the exhibit small pamphlets are given in which attention is directed to the publications of the Survey and the interesting features of the geology of the state.

Besides the Director and the Assistant State Geologist the corps employed in the regular work of the State Survey has been about the same as in previous years. Prof. M. F. Arey, Prof. John L. Tilton, and Prof. Bohumil Shimek did work in areal geology; Dr. S. W. Beyer and assistants carried forward investigations on light burning clays; Prof. W. H. Norton continued to collect data regarding underground waters of the state; and Prof. A. O. Thomas and Dr. F. M. Van Tuyl continued their studies on the Devonian and Mississippian systems of rocks, respectively; Mr. Dayton Stoner continued his work on the rodents of the state, and Dr. B. H. Bailey made further investigations of the hawks and owls of Iowa.

In the Administrative Report for 1914, reference was made to an investigation on the Iowan drift by Dr. W. C. Alden of the United States Geological Survey and Dr. M. M. Leighton of the Iowa Geological Survey. This investigation was undertaken in order to settle, if possible, the question whether or not there is sufficient evidence to justify the recognition of the Iowan drift as a drift sheet separate from the Kansan drift. Field work was begun in 1914 and was continued during the summer of 1915. The investigations have confirmed the contention of Doctor Calvin that in northeastern and in northcentral Iowa there is an Iowan drift. In a paper in Volume XXVI of the Reports of the Survey Doctors Alden and Leighton have presented the field evidence upon which their conclusions are based.

In northwestern Iowa there is a drift region lying outside the distinctive Wisconsin drift, which, on account of its topography and for other reasons, has been found by different geologists to be difficult to interpret satisfactorily. Some have thought that the region is covered with drift of Wisconsin age; some have interpreted the area to be covered with extra-morainic Wisconsin; and still others have thought the drift to be Early Wisconsin, Iowan, or Kansan drift. During several field seasons the Pleistocene deposits of northwestern Iowa, including the deposits of the questionable area, have been studied by Dr. J. E. Carman. He has reached the conclusion that the region which lies outside the Wisconsin moraine is covered by drift of Kansan age. An exhaustive report by Doctor Carman on the Pleistocene deposits of northwestern Iowa is now in press and will be published in Volume XXVI of the Reports of the Survey. This report is accompanied by a map which will be of great value to all persons who are interested in the northwestern part of our state.

One of the essential aids of present-day civilization in its relation to land is maps—good maps, accurate maps, maps which are so made as to show clearly the natural features of the surface, such as rivers and creeks, hills and valleys, forests and swamps, as well as those features due to culture, as cities, schools, roads and bridges. Such maps as these are indispensable in many lines of industry and are of great value to many more. By means of them the railroad construction engineer can lay out the route of his right-of-way without the expense of a preliminary survey, the drainage engineer can plot his irrigation or drainage ditch almost better than on the ground, and the autoist can visualize his trip as intelligently at home as he does later on the road.

It is with a realization of these conditions that the Iowa Geological Survey is coöperating with the United States Geological Survey in the making of such maps for the state of Iowa. There is no doubt that the topographic maps which the United States Geological Survey is preparing and publishing are among the best and most accurate of those issued in any country in the world. It is our misfortune that no larger part of the United States is covered by them than is the case—only about forty per cent, after forty years of work. In Iowa only about twenty-one per cent of the state is included in the area mapped, while seven of her sister states are completely covered and of three others eighty per cent or more is covered.

The usefulness of these maps calls for greater speed in completing the topographic survey of the state and publication of the maps. But to do this increased funds must be available so that larger areas may be surveyed each year than is possible with the limited appropriations now devoted to this work. The anxiety of the Federal Government to coöperate in the work is shown by its offer to duplicate any amount which the state of Iowa will allot to this survey, and in addition it will pay the cost of engraving and printing. At least ten thousand dollars should be spent each year by the state on the field work in order that the mapping may be completed within a reasonable number of years.

The interest which is taken in this work is shown by the fact that at a recent meeting of the Society of Iowa Engineers enthusiastic endorsement was given the project of hastening the topographic survey of the state. Also similar support was given by the Iowa Academy of Science. Teachers of geography over the state also are interested in this work and its consequent aid in their teaching.

During the year 1915 the Survey continued to coöperate with the Water Resources Branch of the United States Geological Survey in the work of stream gaging and discharge measurements of the important streams of the state.

As in former years, the Iowa Geological Survey coöperated in 1915 with the United States Geological Survey in the preparation of statistics of mineral production in Iowa. The value of the output for the year was $27,062,950, which is the highest figure of record for the state, and exceeds the value of the output for 1914 by $761,085. Year by year, for several years, the value of the mineral output of Iowa has increased. During the three years previous to 1915 the values of the outputs were as follows: In 1912, $22,910,266; in 1913, $25,612,345; and in 1914, $26,301,865; a decade ago, in 1906, the value of the output was only $16,414,447.

Coal continues to be the chief mineral produced in Iowa, clay and clay products ranks second, cement ranks third, and gypsum, fourth. In 1915 these four products had a value of $25,664,846, which is somewhat more than ninety-five per cent of the total value of all the mineral products. In 1915 the value at the mines of the output of coal was $13,577,608; in 1914, the value was $13,364,070. The total tonnage of coal mined in 1915 was 7,614,143, compared with the tonnage of 7,451,022 in 1914. The five leading coal-producing counties in 1915 in order of tonnage were Monroe, Polk, Appanoose, Lucas, and Marion. These five counties produced more than six million tons, Monroe county alone having produced more than two million tons. For the first time in recent years Lucas county now occupies an important place among the coal producing counties of the state. The average number of men employed in coal mining in Iowa in 1915 was 15,549.

The value of clay and clay products in 1915 was $6,749,088, a figure which has never been exceeded in the history of the clay industry in the state. The values of the clay products in the three chief clay producing counties were as follows: Cerro Gordo county, $1,830,220; Webster county, $1,256,981; and Polk county, $791,371. Woodbury county ranked fourth, and Dallas county, fifth. Iowa's production of drainage tile alone in 1915 had a value of $3,802,579; in 1914 the value was $3,180,836.

In 1915 the three cement plants of Iowa, two of which are at Mason City, the third at Des Moines, produced cement to the value of $4,119,952, which is the record figure for the state.

The value of sand and gravel in 1915 was $720,795, of stone and lime $577,295, of mineral waters $18,534, and of other products, which includes sand-lime brick, mineral paints and natural gas, $21,550.

Iowa continues to be an important producer of gypsum. In 1915 the value of the output was $1,278,128. Although New York state produces a greater quantity of gypsum than does Iowa, the value of the Iowa product exceeds the value of the output of New York. The total production of gypsum in Iowa comes from Webster county, where the evidence indicates that there is an abundant supply for future needs. There is an important deposit of gypsum at Centerville, but thus far no production has come from this locality. The main reason is the difficulty in handling the large amount of water which enters the shaft a few feet above the gypsum. So important are the gypsum deposits of Iowa that the Board, at its last meeting, approved the plan of having them fully described in a report to be published by the Survey. A monograph will be prepared by Dr. Frank A. Wilder, who was at one time State Geologist of Iowa, and who for more than ten years has been President of the Southern Gypsum Company of North Holston, Virginia. The report of Doctor Wilder will be awaited with interest since he is a recognized authority on the subject of gypsum and the gypsum industry.

The office of the Survey continues to render splendid service to the citizens of the state. Among the kinds of service rendered the following may be mentioned:

1. Replying to scores of letters in which information is asked with reference to the geology and mineral resources of the state. In much of this correspondence questions are asked with reference to local geology.

2. Furnishing information in regard to state reports and other publications dealing with the geology and mineral resources of the various sections of the state.

3. Examining and reporting on numerous specimens of minerals and fossils which are submitted by the citizens of the state. Advice is given as to whether or not the minerals are of value or are likely to be found in sufficient quantity to be of commercial importance.

4. Giving advice with regard to reliable firms where analyses and other tests may be made to establish the commercial value of any mineral deposit.

5. Trying to prevent an unfounded rumor from gaining acceptance in the public mind with regard to the reputed discovery of gas, oil, or other product before it leads to large losses and unnecessary excitement.

6. Giving geological facts to city officials, railway companies, and private citizens with regard to water supplies, availability of road materials, etc.

7. Informing citizens regarding the advisability or inadvisability of spending time and investing money in the development of particular deposits of mineral within the state.

I take pleasure in submitting to you the following papers, and recommend that they be published as Volume XXVI, which is the Twenty-fourth Annual Report of the Iowa Geological Survey:

Mineral Production in Iowa in 1915. By George F. Kay.

River Waters in Iowa: A Preliminary Report. By George A. Gabriel.

The Iowan Drift: A Review of the Evidences of the Iowan Stage of Glaciation. By W. C. Alden and M. M. Leighton.

Pleistocene Deposits Between Manilla in Crawford County and Coon Rapids in Carroll County. By George F. Kay.

The Pleistocene Geology of Northwestern Iowa. By J. Ernest Carman.

Respectfully submitted,

George F. Kay,
State Geologist.

MINERAL PRODUCTION IN IOWA FOR 1915

BY GEORGE F. KAY

MINERAL PRODUCTION IN IOWA FOR 1915[1]

BY GEORGE F. KAY.

VALUE OF MINERAL PRODUCTION.

1913.

Coal	$13,496,710
Clay and clay products	5,575,581
Stone and lime	854,814
Gypsum	1,157,939
Lead and zinc	4,150
Mineral waters	7,369
Sand and gravel	528,066
Cement	3,972,876
*Other products	14,840
Total	$25,612,345

1914.

Coal	$13,364,070
Clay and clay products	6,405,995
Stone and lime	594,681
Gypsum	1,321,457
Lead and zinc	
Mineral waters	30,179
Sand and gravel	556,868
Cement	4,008,915
*Other products	19,700
Total	$26,301,865

1915.

Coal	$13,577,608
Clay and clay products	6,749,088
Stone and lime	577,295
Gypsum	1,278,128
Lead and zinc	
Mineral waters	18,534
Sand and gravel	720,795
Cement	4,119,952
*Other products	21,550
Total	$27,062,950

*Sand-lime brick, mineral paints and natural gas.

[1]The mineral statistics were compiled by the Iowa Geological Survey in co-operation with the United States Geological Survey.

In 1915 the value of the mineral production in Iowa was $27,062,950. This is the highest figure of record for the state, exceeding the value of production in 1914 by $761,085. The following table shows the value of Iowa's mineral output during each of the past 10 years:

VALUE OF MINERAL PRODUCTION IN IOWA FOR THE YEARS 1906 TO 1915 INCLUSIVE.

1906	$16,414,447
1907	17,627,925
1908	18,090,447
1909	20,365,721
1910	22,744,572
1911	21,119,111
1912	22,910,066
1913	25,612,345
1914	26,301,865
1915	27,062,950

From this table it will be seen that the value of the output in 1915 exceeded the value of a decade earlier by $10,648,503. With the exception of the year 1911, the value of each year of the past ten years has been greater than that of the preceding year.

The four most important products of Iowa in order of their value of production are coal, clay and clay products, cement and gypsum. These products in 1915 had a value of $25,724,776, which was ninety-five per cent of the total value of all the mineral products of the state. The values of coal, clay and clay products, sand and gravel, and cement were greater in 1915 than in 1914 but the values of stone and lime, gypsum, and mineral waters were less in 1915 than in 1914.

The number of mineral producers in Iowa in 1915 was 540; the number in 1914 was 563.

The total production by counties for 1915 is given in Table I.

TABLE I

Value of Total Mineral Production, By Counties, for 1915.

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products	Total
Adair	1		*				*
Adams	5	$ 21,300					$ 21,300
Allamakee	4		*	$ 4,123			*
Appanoose	55	2,376,497	*	*			2,401,406
Audubon	5		*		$ 205		*
Benton	6		*	*			*
Black Hawk	12			8,028	60,315	*	*
Boone	12	329,676	$ 128,257		*		*
Bremer	4				1,760		1,760
Buena Vista	5		*		*		*
Butler	2				*		*
Calhoun	1		*				*
Carroll	1				*		*
Cass	1		*				*
Cedar	1		*				*
Cerro Gordo	10		1,830,220	*		*	5,076,994
Cherokee	4				25,301		25,301
Chickasaw	1				*		*
Clay	1		*				*
Clayton	3			*	*		*
Clinton	7		*	*	15,545		24,270
Dallas	11	905,355	*				*
Delaware	1		*				*
Des Moines	6		*	*	16,802		37,667
Dickinson	3				*	*	*
Dubuque	16		20,337	68,512	19,674		108,523
Emmet	1				*		*
Fayette	5		*	*	14,218		31,156
Floyd	3		*	*	*		*
Franklin	6		*		1,100		*
Fremont	1		*				*
Greene	2	*					*
Grundy	1		*				*
Guthrie	6	10,887	*				*
Hamilton	2		*				*
Hancock	2		*				*
Hardin	6		*	*	9,900		94,114
Harrison	1			*			*
Henry	3		*	*			*
Howard	2		*	*	*		*
Humboldt	2		*				*
Ida	2				*		*
Iowa	2		*				*
Jackson	3			*	*		*
Jasper	11	555,030	*			*	592,301
Jefferson	6	*	29,493			*	34,008
Johnson	4		*		*		*
Jones	9		*	72,058	*		91,081
Keokuk	9	*	*				*

TABLE I—Continued

Counties	No. of Producers	Coal	Clay and Clay Products	Stone and Lime	Sand and Gravel	Other Products	Total
Kossuth	2	----------	*	--------	*	---------	*
Lee	9	----------	*	53,842	*	---------	62,327
Linn	11	----------	25,675	*	34,695	---------	*
Louisa	5	----------	*	*	--------	$ 250	8,400
Lucas	1	*	----------	--------	--------	---------	*
Lyon	3	----------	----------	--------	39,921	---------	39,921
Madison	2	----------	----------	*	--------	---------	*
Mahaska	14	395,629	*	--------	--------	---------	*
Marion	20	552,968	*	--------	14,114	---------	*
Marshall	5	----------	*	*	*	---------	*
Mills	4	----------	3,775	--------	--------	---------	3,775
Mitchell	2	----------	----------	*	--------	---------	*
Monroe	17	3,418,329	*	--------	--------	---------	*
Montgomery	1	----------	----------	*	--------	---------	*
Muscatine	9	----------	14,884	*	46,482	---------	*
O'Brien	4	----------	----------	--------	5,836	---------	5,836
Osceola	2	----------	----------	--------	*	---------	*
Page	3	*	*	--------	--------	---------	*
Palo Alto	3	----------	----------	--------	30,022	---------	30,022
Plymouth	6	----------	*	--------	12,484	---------	*
Pocahontas	1	----------	----------	*	--------	---------	*
Polk	44	3,255,677	791,371	--------	146,636	*	*
Pottawattamie	3	----------	23,303	--------	--------	---------	23,303
Poweshiek	4	----------	37,147	--------	--------	---------	37,147
Sac	3	----------	*	--------	*	---------	*
Scott	13	----------	30,833	119,646	*	*	*
Sioux	5	----------	----------	--------	8,510	---------	8,510
Story	5	----------	*	--------	6,997	---------	*
Tama	6	----------	55,458	--------	--------	---------	55,458
Taylor	2	*	----------	--------	--------	---------	*
Union	1	----------	*	--------	--------	---------	*
Van Buren	7	*	*	*	*	---------	*
Wapello	17	549,467	83,662	*	*	*	654,431
Warren	3	*	*	--------	--------	---------	*
Washington	4	----------	40,282	--------	--------	---------	40,282
Wayne	1	*	----------	--------	--------	---------	*
Webster	21	41,025	*	--------	*	1,289,428	2,581,223
Winnebago	2	----------	*	--------	*	---------	*
Winneshiek	2	----------	*	--------	*	---------	*
Woodbury	3	----------	*	--------	*	*	*
Wright	3	----------	*	--------	*	---------	*
County values representing less than three producers and small coal mines	----	1,165,768	3,634,391	251,086	210,278	4,148,486	14,961,134
Totals	540	$ 13,577,608	$ 6,749,088	$ 577,295	$ 720,795	$5,438,164	$27,062,950

*Included in County values and totals.

COAL.

Coal has been for many years the chief mineral mined in Iowa, the yearly production for several years having varied up and down between 7,000,000 and 8,000,000 tons. In 1915 the production was 7,614,143 tons with a value of $13,577,608 at the mines. The five leading coal producing counties in order of tonnage in 1915 were Monroe, Polk, Appanoose, Lucas and Dallas. It is of interest to note that Lucas county now ranks fourth, whereas Mahaska county, which for many years previous to 1914 ranked fourth, dropped to eighth place in 1915. Dallas, Jasper, Marion, Polk and Wapello counties produced a considerably larger tonnage in 1915 than in 1914.

The chief use of Iowa coal is by the railways and for domestic purposes, and the Iowa coal now has keen competition on the markets of Iowa with coal from other states.

The average price of coal at the mines during the year 1915 was $1.78.

In 1915 there were 15,549 men employed in coal mining in Iowa, in 1914 there were 16,057.

The output, disposition of product, value, average price per ton, average number of days worked, and average number of men employed in 1915 are given, tabulated by counties, in Table II.

TABLE II

Coal Production for Iowa in 1915, By Counties, in Short Tons.

Counties	Loaded at Mine for Shipment	Sold to Local Trade and Used by Employees	Used at Mine for Steam and Heat	Total Quantity	Total Value	Average Price Per Ton	Average Number of Days Active	Average Number of Employees
Adams		8,120		8,340	$ 21,300	$ 2.55	174	45
Appanoose	1,147,423	57,508	20,619	1,225,100	2,376,497	1.94	245	4,139
Boone	109,731	41,384	5,145	156,260	329,676	2.11	195	447
Dallas	449,262	11,219	10,400	470,881	905,355	1.92	214	863
Guthrie	------------	3,968	------------	3,968	10,887	2.74	157	27
Jasper	252,096	15,961			555,030	2.07	223	514
Mahaska	229,403	13,765	2,618	245,786	395,629	1.61	192	432
Marion	322,242	28,116	9,797	360,155	552,968	1.54	218	782
Monroe	2,058,876	40,841	57,632	2,157,349	3,418,329	1.87	206	3,704
Polk	1,509,531	203,685	31,088	1,744,304	3,255,677	------------	223	2,932
Wapello	293,717	15,626	4,650	313,993	549,467	------------	179	589
Webster	12,380		------------		41,025	------------	147	79
*Counties with less than three producers and small mines	578,917	62,093	6,450	928,007	1,165,768	------------	------------	1,075
Total	6,963,698	502,286	148,159	7,614,143	$13,577,608	$ 1.78	220	15,549

*Greene, Jefferson, Keokuk, Lucas, Page, Taylor, Van Buren, Warren, Wayne.

Iowa's rank as a coal producing state in 1915 is given in the following table. From this table it is seen that Iowa ranked tenth in tonnage and ninth in value. The same relations prevailed in 1914.

RANK OF LEADING COAL-PRODUCING STATES IN 1915, WITH QUANTITY AND VALUE OF PRODUCT AND PERCENTAGE OF EACH[2].

PRODUCTION.

Rank	State	Quantity (short tons)	Percentage of Total Production
1	Pennsylvania:		
	Anthracite	88,995,061	16.8
	Bituminous	157,955,137	29.7
2	West Virginia	77,184,069	14.5
3	Illinois	58,829,576	11.1
4	Ohio	22,434,691	4.2
5	Kentucky	21,361,674	4.0
6	Indiana	17,006,152	3.2
7	Alabama	14,927,937	2.8
8	Colorado	8,624,980	1.6
9	Virginia	8,122,596	1.5
10	Iowa	7,614,143	1.4

VALUE

Rank	State	Value	Percentage of Total Value
1	Pennsylvania:		
	Anthracite	$184,653,498	26.9
	Bituminous	167,419,705	24.4
2	West Virginia	74,561,349	10.8
3	Illinois	64,622,471	9.4
4	Ohio	24,207,075	3.5
5	Kentucky	21,494,008	3.1
6	Alabama	19,066,043	2.8
7	Indiana	18,637,476	2.7
8	Colorado	13.599,264	2.0
9	Iowa	13,577,608	2.0
10	Kansas	11,360,630	1.6

[2]From Advance Chapters of Mineral Resources of the United States for 1915.

CLAY AND CLAY PRODUCTS.

The value of clay and clay products in Iowa in 1915 was $6,749,088, a figure that has not been exceeded in the history of the clay industry in the state. Previous to 1915 the year 1914 held the record for value of production, in which year the value was $6,405,995.

The following table shows the value of clay and clay products of Iowa during each year from 1906 to 1915.

PRODUCTION OF CLAY AND CLAY PRODUCTS IN IOWA FROM 1906 TO 1915.

Year	Value
1906	$3,477,237
1907	3,733,476
1908	4,078,627
1909	4,916,513
1910	5,335,036
1911	4,436,839
1912	4,524,492
1913	5,575,581
1914	6,405,995
1915	6,749,088

The output of clay and clay products in 1914 and 1915 was distributed as follows:

Product	1914		1915	
	Quantity in Thousands	Value	Quantity in Thousands	Value
Common brick	143,534	$1,067,746	125,752	$ 898,851
Paving brick or block	14,997	211,905	30,573	300,785
Face brick	11,183	148,394	11,916	153,324
Drain tile		3,180,836		3,802,599
Sewer pipe		558,751		448,721
Fireproofing		1,083,397		1,008,457
Other products		150,716		130,878
Clay		4,250		5,473
Total		$6,405,995		$ 6,749,088

The clay product in 1915 is tabulated by counties in Table III, in which the distribution of the leading products is given.

TABLE III

Value of Iowa Clay and Clay Products for 1915, Tabulated By Counties

Counties	No. of Producers	Common Brick	Paving Brick or Block	Face Brick	Drain Tile	Other Products†	Total Value
Adair	1	*			*		*
Allamakee	1					*	*
Appanoose	1	*					*
Audubon	2	*			*	*	*
Benton	5	$ 4,050			$ 28,894	*	*
Boone	3	43,192	*	*	*	*	128,257
Buena Vista	3	*			25,577		*
Calhoun	1	*			*	*	*
Cass	1	*			*	*	*
Cedar	1	*			*		*
Cerro Gordo	7	25,856			1,417,908	$ 386,456	1,830,220
Clay	1	*			*		*
Clinton	2	*			*		*
Dallas	6	5,394		*	221,346	57,240	*
Delaware	1	*					*
Des Moines	1	*			*		*
Dubuque	3	20,337					20,337
Fayette	1	*			*	*	*
Floyd	1	*			*	*	*
Franklin	1	*			*	*	*
Fremont	1	*					*
Grundy	1	*		*			*
Guthrie	2	*			*	*	*
Hamilton	2	*			*	*	*
Hancock	1				*		*
Hardin	1				*		*
Henry	2	*			*	*	*
Howard	1	*			*	*	*
Humboldt	1				*		*
Iowa	2	*			*		*
Jasper	4	6,850			16,300	*	*
Jefferson	3	*			23,402	*	29,493
Johnson	2	*			*		*
Jones	2	*			*	*	*
Keokuk	8	2,648			175,689	*	*
Kossuth	1	*			*	*	*
Lee	3	2,980		*			*
Linn	4	20,855			4,820		25,675
Louisa	1	*			*	*	*
Mahaska	2	*	*		*	*	*
Marion	4	6,177	*		25,777	46,247	*
Marshall	2	*			*	*	*
Mills	4	3,775					3,775
Monroe	1				*	*	*
Muscatine	4	12,384			*	*	14,884

TABLE III—Continued

Counties	No. of Producers	Common Brick	Paving Brick or Block	Face Brick	Drain Tile	Other Products†	Total Value
Page	2	*	----------	--------	*	*	*
Plymouth	1	*	----------	--------	---------	---------	*
Polk	10	140,195	204,744	*	151,233	*	791,371
Pottawattamie	3	23,303	----------	--------	---------	---------	23,303
Poweshiek	4	3,036	*	--------	30,722	*	37,147
Sac	1	*	----------	--------	*	*	*
Scott	4	8,385	*	--------	*	*	30,833
Story	2	*	*	*	*	*	*
Tama	6	16,186	----------	*	25,222	*	55,458
Union	1	*	----------		*	*	*
Van Buren	2	*	----------	--------	*	*	*
Wapello	3	27,790	*	5,050	*	*	83,662
Warren	2	*	----------	--------	*	*	*
Washington	4	7,942	----------	--------	23,324	9,016	40,282
Webster	10	71,690	*	--------	696,829	478,412	*
Winnebago	1	----------	----------	--------	*	---------	*
Winneshiek	1	*	----------	--------	---------	---------	*
Woodbury	1	*	*	--------	---------	*	*
Wright	1	*	----------	--------	*	---------	*
**Pottery and clay sold	----	----------	----------	--------	---------	---------	10,898
Counties with less than three producers	----	445,826	96,041	148,324	935,556	605,336	3,623,493
Totals	161	$ 898,851	$ 300,785	$153,324	$3,802,599	$1,582,707	$6,749,088

†Includes sewer pipe, fireproofing, etc.
*Included in "Counties with less than three producers."
**Black Hawk, Hardin, Muscatine, Wapello, Webster and Woodbury counties.

The following table shows the rank of the ten leading states in value of clay products in 1915. It includes also the number of operating firms and the percentage of the total value produced by each of the ten states:

TEN LEADING STATES IN VALUE OF CLAY PRODUCTION IN 1914 AND 1915[3].

1914.

State	Rank	Number of Operating Firms Reporting	Value not including Raw Clay Sold	Percentage of Total Value
Ohio	1	543	$37,166,768	22.53
Pennsylvania	2	369	21,846,996	13.24
New Jersey	3	148	16,484,652	9.99
Illinois	4	263	13,318,953	8.07
New York	5	205	9,078,933	5.50
Indiana	6	240	7,655,285	4.64
Iowa	7	171	6,401,745	3.88
Missouri	8	98	6,077,284	3.68
West Virginia	9	58	5,761,411	3.49
California	10	84	4,461,661	2.70

1915.

State	Rank	Number of Operating Firms Reporting	Value not including Raw Clay Sold	Percentage of Total Value
Ohio	1	524	$36,839,621	22.58
Pennsylvania	2	352	22,726,031	13.93
New Jersey	3	149	15,965,418	9.79
Illinois	4	247	14,791,938	9.07
New York	5	192	9,489,002	5.82
Indiana	6	221	7,090,630	4.35
Iowa	7	161	6,743,615	4.13
Missouri	8	58	6,284,527	3.85
West Virginia	9	89	5,431,569	3.33
California	10	82	3,599,375	2.21

From this table it will be seen that in 1915 Iowa ranked seventh among the states of the country.

[3]Advance Chapter from Mineral Resources of the United States for 1915.

The three principal clay products in order of value in 1915 were drain tile, fireproofing and common brick. Cerro Gordo county continued to be the chief producer of clay and clay products, the value of the output in 1915 being $1,830,220, to which value drain tile alone contributed $1,417,908.

The value of drain tile and common brick sold in Iowa in the past ten years has been as follows:

PRODUCTION OF DRAIN TILE AND COMMON BRICK IN IOWA FROM 1906 TO 1915.

Year	Drain Tile	Common Brick
1906	$ 1,721,614	$ 1,125,009
1907	2,011,793	1,085,383
1908	2,522,363	896,890
1909	2,830,910	1,072,340
1910	3,457,455	1,088,266
1911	2,468,962	1,025,011
1912	2,293,084	1,017,097
1913	2,798,816	1,052,036
1914	3,180,836	1,067,746
1915	3,802,599	898,851

STONE AND LIME.

The value of stone and lime produced in Iowa in 1915 was $577,295. The distribution of output in 1915 with the distribution in 1914 for comparison is as follows:

	1914	1915
Limestone—		
Building	$ 32,332	$ 32,665
Riprap and rubble	96,482	106,064
Crushed Stone—		
Road making	17,438	28,315
Railroad ballast	97,747	78,886
Concrete	278,071	261,541
*Other purposes	15,292	28,185
Lime	56,000	41,120
Total limestone and lime	$ 593,362	$ 576,776
Sandstone	1,319	519
Total stone and lime	$ 594,681	$ 577,295

*Paving, curbing, flagging, etc.

The distribution of limestone and lime in 1915 is given by counties in Table IV.

TABLE IV

Production of Limestone and Lime in 1915.

Counties	No. of Producers	Building Stone	Riprap and Rubble	Crushed Stone			Lime	Other Uses	Total Value
				Road making	Railroad Ballast	Concrete			
Allamakee	3	*						*	$ 4,123
Appanoose	1			*					*
Benton	1					*			*
Black Hawk	5	*		*		$ 3,526		*	8,028
Cerro Gordo	1		*					*	*
Clayton	2	*		*		*			*
Clinton	1	*	*						*
Des Moines	2		*						*
Dubuque	9	$ 4,190	$ 28,908	*		*	*	*	68,512
Fayette	1	*							*
Floyd	1		*						*
Hardin	2					*			*
Harrison	1	*							*
Henry	1	*		*					*
Howard	1	*		*		*			*
Jackson	2			*			*		*
Jones	5	*	11,467	*	*	43,728		*	72,018
Lee	4		14,237	*		*		*	53,842
Linn	2		*	*	*	*		*	*
Louisa	1	*							*
Madison	2		*			*		*	*
Marshall	2		*		*				*
Mitchell	2	*	*			*			*
Montgomery	1							*	*
Muscatine	1		*						*
Pocahontas	1					*			*
Scott	6	*	23,990	*	*	79,327		*	119,167
Van Buren	2	*							*
Wapello	1		*	*					*
Counties with less than three producers		28,475	27,462	$ 28,315	$ 78,886	134,960	$ 41,120	$ 28,185	251,086
Total		$ 32,665	$ 106,064	$ 28,315	$ 78,886	$ 261,541	$ 41,120	$ 28,185	$ 576,776

*Included in "Counties with less than three producers."

SAND AND GRAVEL.

The value of sand and gravel produced in Iowa in 1915 was $720,795. The value of output for the previous year was only $556,868.

The sand and gravel sold in 1915 may be classified as follows, and in order that comparison may be made with 1914 the classification for that year is given also:

Kind—	1914 Value	1915 Value
Sand used for—		
Molding	$ 2,365	$ 160
Building	272,445	262,587
Engine	3,250	9,353
Other sand	72,988	135,368
Gravel	205,820	313,327
Total sand and gravel	$ 556,868	$ 720,795

Table V shows the distribution of sand and gravel by counties in 1915.

TABLE V

Value of Sand and Gravel Produced in Iowa in 1915.

Counties	No. of Producers	Molding Sand	Building Sand	Engine Sand	Other Sand	Gravel	Total
Audubon	3	----	$ 205	----	----	----	$ 205
Black Hawk	6	----	7,375	----	----	$ 52,940	60,315
Boone	1	----	*	----	----	*	*
Bremer	4	----	*	----	----	1,310	1,760
Buena Vista	2	----	----	----	----	*	*
Butler	2	----	*	----	----	*	*
Carroll	1	----	----	----	----	*	*
Cherokee	3	----	11,900	----	*	*	25,301
Chickasaw	1	----	----	----	----	*	*
Clayton	1	----	----	----	*	----	*
Clinton	6	----	3,046	----	----	12,499	15,545
Des Moines	3	----	*	*	*	*	16,802
Dickinson	2	----	*	----	----	*	*
Dubuque	4	----	6,649	----	----	*	19,674
Emmet	1	----	----	----	----	*	*
Fayette	3	----	*	----	*	----	14,218
Floyd	1	----	----	----	----	*	*
Franklin	5	----	598	----	*	475	1,100
Hardin	3	----	*	*	*	*	9,900
Howard	1	----	----	----	----	*	*
Ida	2	----	*	----	----	----	*
Jackson	1	----	*	----	----	*	*
Johnson	2	----	*	----	*	*	*
Jones	1	----	----	----	----	*	*
Kossuth	1	----	*	----	----	----	*
Lee	2	----	*	*	----	----	*
Linn	5	----	*	----	----	18,451	34,695
Lyon	3	----	*	----	*	12,509	39,921
Marion	3	----	*	----	----	*	14,114
Marshall	1	----	*	*	*	*	*
Muscatine	4	----	*	----	$ 10,055	21,427	46,482
O'Brien	4	----	3,530	----	*	*	5,836
Osceola	2	----	*	----	----	*	*
Palo Alto	3	----	*	----	*	*	30,022
Plymouth	5	----	3,884	----	*	2,100	12,484
Polk	13	----	70,482	$ 3,492	49,345	23,317	146,636
Sac	2	----	*	*	*	*	*
Scott	1	----	*	----	----	----	*
Sioux	5	----	5,240	----	----	*	8,510
Story	3	----	*	----	*	*	6,997
Van Buren	1	----	*	----	----	----	*
Wapello	2	*	*	----	*	*	*
Webster	2	----	*	----	*	*	*
Winnebago	1	----	*	----	----	----	*
Winneshiek	1	----	*	----	*	*	*
Woodbury	1	----	*	----	----	----	*
Wright	2	----	*	----	----	*	*
Counties with less than three producers	----	160	149,678	5,861	75,968	168,299	210,278
Total	----	$ 160	$ 262,587	$ 9,353	$ 135,368	$ 313,327	$ 720,795

*Included in "Counties with less than three producers."

GYPSUM.

In 1915 the value of gypsum produced in Iowa was $1,278,128; in 1914 the value of the output was $1,321,457. Although New York produces a greater quantity of gypsum yearly than Iowa produces, the value of the Iowa product now exceeds the value of the output of New York. Iowa, therefore, ranks first in value of production among the states producing gypsum in the United States. The total production of gypsum in the state comes from Webster county, where the evidence indicates that there is an abundant supply for future needs.

There is an important deposit of gypsum at Centerville, but thus far no production has come from this locality. The main reason for the lack of production is the difficulty in handling the large amount of water which enters the shaft a few feet above the gypsum.

The value of the gypsum produced in Iowa during each of the past ten years is as follows:

PRODUCTION OF GYPSUM IN IOWA FROM 1906 TO 1915 INCLUSIVE.

Year	Value
1906	$ 573,498
1907	730,383
1908	564,688
1909	655,602
1910	943,849
1911	871,752
1912	845,628
1913	1,157,939
1914	1,321,457
1915	1,278,128

The principal items of production and distribution in 1915, and for 1914 for comparison, are as follows:

	1914		1915	
	Short Tons	Value	Short tons	Value
Crude gypsum mined	480,404		495,860	
Distributed as follows:				
Sold crude—				
To Portland cement mills, as land plaster, etc.	65,185	$ 60,486	71,909	$ 59,930
Sold calcined—				
As hard wall plaster	265,619	1,109,570	256,063	1,057,546
As stucco, plaster of Paris, etc.	69,446	151,401	78,994	160,652
Total sold calcined	335,065	$ 1,260,971	335,057	$ 1,218,198
Total sold	400,250	$ 1,321,457	406,966	$ 1,278,128

LEAD AND ZINC.

In 1915 there was no production of lead and zinc in the state.

MINERAL WATERS.

The value of mineral waters sold in Iowa in 1915 was $18,534; in 1914 the value was $30,179. There were eight commercial springs in 1915, from which 198,739 gallons were sold for medicinal and table uses. The average price per gallon was nine cents. The eight springs reporting sales are as follows:

Colfax Mineral Spring, Colfax, Jasper county.
Colfax Grand Spring, Colfax, Jasper county.
Crystal Spring, Estherville, Emmet county.
Egralharve Spring, Montgomery, Dickinson county.
Hawkeye Hygeia Spring, Sioux City, Woodbury county.
Hestons Spring, Jefferson county.
Red Mineral Springs, Eddyville, Wapello county.
White Sulphur Spring, near Davenport, Scott county.

PORTLAND CEMENT.

In 1915 the three cement plants of Iowa, two of which are at Mason City, the third at Des Moines, produced cement to the value of $4,119,952, which is the record figure for the state.

The figures for the quantity and value of the Portland cement shipped by the ten leading states in 1915 are as follows:

SHIPMENT OF PORTLAND CEMENT BY STATES, 1915[4]

State	Shipping Plants	Quantity (barrels)	Value	Average Price per Barrel
Pennsylvania	20	28,188,450	$20,252,961	$ .718
Indiana	5	8,577,513	7,336,821	.855
Illinois	5	5,435,655	4,884,026	.899
New York	8	5,275,101	4,039,215	.766
Michigan	11	4,727,768	4,454,608	.942
Missouri	5	4,628,484	4,007,679	.866
Iowa	3	4,590,336	4,119,952	.898
California	7	4,532,452	6,338,918	1.399
Kansas	10	3,780,735	2,826,443	.748
Ohio	5	1,961,409	1,917,920	.978
Total (ten states)	79	71,697,903	$60,178,543	
Total (other states)	32	15,196,778	14,578,131	

NATURAL GAS.

The production of natural gas in Iowa in 1915 came from four shallow wells in Louisa county. The gas is obtained from sand pockets in the glacial deposits, and is used for lighting three dwellings. In many places in Iowa small amounts of gas have been found having the same relations to the drift deposits as has the gas of Louisa county. Gas in commercial quantities has not yet been found in any of the wells that have been drilled for water in the indurated rocks of the state.

IRON ORE.

In 1915 the Missouri Iron Company continued its investigations on the Waukon iron ores, but no ore was placed upon the market.

[4]Advance chapter from mineral resources of the United States for 1915.

RIVER WATERS IN IOWA

A PRELIMINARY REPORT

BY

GEORGE A. GABRIEL

CONTENTS

RIVER WATERS IN IOWA

PRELIMINARY REPORT

Introduction.

Nearly every kind of industrial establishment requires water in some form or other. In case the water is to be used for domestic purposes, its value is its potability as determined by its freedom from dangerous or bad tasting or smelling organisms; but in its application to industrial purposes, the biologic features are secondary except in a very few industries like paper manufacture, breweries and the like. The real suitability of the water depends upon the mineral contents, dissolved or suspended in it. It is well known that water dissolves more or less of everything it comes in contact with, hence the purity of a water depends on its locality. Waters which have traversed limestone regions are hard; those from alkali regions are alkaline; those from swamps usually are highly colored and contain a large amount of organic matter; those from drainage ditches are almost always badly polluted and are necessarily unpotable. Therefore, in the industrial application of water it is essential to study its composition in reference to its adaptability to any particular industry.

The great importance of the mineral contents of water has led the Geological Survey of Iowa to study the composition of a few of the rivers in Iowa, with special reference to the high and low periods of the river. This investigation was undertaken during the late spring and summer of 1913, and the results of this work are incorporated in this report.

Methods of Examination.

It is generally recognized in sampling water that the mineralization of the water may change even 100 per cent while the samples are being gathered; therefore we did not feel justified in employing methods which were expensive and would make the cost of the work prohibitive, since we could not at the least expect our samples from the same river to agree within 10 per cent. Therefore, we employed methods which were moderately accurate and at the same time easy of manipulation with considerable speed. None of the methods are new and all are recognized by competent authorities.

COLLECTION OF SAMPLES.

The waters from the rivers above any possible contamination of sewage, etc., were collected in gallon glass jugs and shipped direct to the Experiment Station at Ames, Iowa, and usually the water was in the hands of the analyst inside of three days. Particular attention was taken in gathering the samples that the sample of water was taken as near midstream as possible. Collection was usually done from boats.

TURBIDITY.

The determination of turbidity was made upon all samples of water gathered. All turbidity tests were conducted according to method described by the American Public Health Association in its bulletin of Vol. 30, pt. 2, 1905. The standard recommended by this association consists in suspending one gram of thoroughly dried precipitated Fuller's earth in one litre of distilled water. Such a standard has a turbidity of 1000 parts per million. Turbidities below this standard can be made by the usual method.

TOTAL SUSPENDED SOLIDS.

The total suspended matter was determined by use of the Gooch crucible as described in above mentioned bulletin. Usually 500 to 1000 cc. of water was used in this determination, yet in some samples the suspended solids were so high we were obliged to resort to smaller samples.

TOTAL DISSOLVED SOLIDS.

The total dissolved solids were determined in each case in 500 cc. of the sample, which was evaporated to dryness on the water bath in a tarred platinum dish, dried at 180°C for one hour, cooled and weighed. The residue was computed to parts per million.

In American Public Health Association Bulletin, Vol. 30, pt. 2, p. 43, 1905, it is recommended to dry solids at 103°C for one-half hour, but our results seem to warrant the higher temperature. One great advantage of the higher temperature is that the solids more nearly represent the conditions under which the solids are deposited in steam boilers.

Silica.—The residue from the determination of total dissolved solids was heated gently to destroy all organic matter, then treated with hydrochloric acid (1-1) and heated on the water-bath for about fifteen minutes. It was evaporated to dryness, and the residue was treated with 2 to 4 cc. of acid, diluted with water, heated on water-bath and filtered. The insoluble matter remaining upon the filter paper was thoroughly washed with hot water containing a small amount of hydrochloric acid, ignited in a tarred platinum crucible and weighed. It was then treated with a few drops of concentrated sulphuric acid, and hydrofluoric acid which upon being gently heated volatilizes the silica. After this had been accomplished, the crucible was again ignited, cooled and weighed to a constant weight. The part volatilized was computed to parts per million of SiO_2.

Iron.—The iron in the filtrate from the determination of silica was oxidized by addition of a few drops of concentrated nitric acid to the boiling solution. After a slight excess of ammonia had been added, the solution was boiled a few moments to allow the iron and aluminum hydroxide to precipitate. After filtration, the precipitate was washed with water containing a few drops of ammonium chloride. The precipitate was then dissolved in hydrochloric acid containing a small amount of nitric acid, boiled and the iron was determined calorimetrically.

Calcium.—The filtrate from the determination of iron was usually diluted to 100 cc. and divided into two portions, one for the determination of the calcium and magnesium and the other for the determination of alkalies and sulphates.

After the portion for calcium was boiled it was made alkaline with ammonia water; then there was added enough ammonium oxalate to convert all the calcium and magnesium to oxalates. The solution was then heated on the water-bath for three or four hours to insure complete precipitation of the calcium and to dissolve the magnesium oxalate. The precipitate was then filtered and washed with water containing a small amount of ammonia. The flask which had contained the precipitate was placed beneath the funnel containing the precipitate and this was dissolved in dilute sulphuric acid (1-3), the solutions were diluted to 90-100 cc. and titrated against standard potassium permanganate solution, observing the usual precautions. The calcium found was calculated to parts per million of water.

Magnesium.—The filtrate from the calcium was made slightly acid with hydrochloric acid, and evaporated until the salts began to crystallize. An excess of 10 to 15 per cent solution of sodium ammonium phosphate was added and the liquid was allowed to cool. When it was cool, the solution was made distinctly alkaline with strong ammonium hydrate and was allowed to stand six to twelve hours for the complete separation of the magnesium. The solution was then filtered, the precipitate was washed with water containing ammonia until the wash water was free from phosphates. The precipitate was then dissolved in dilute acetic acid solution (5 per cent) and boiling water. Five or six cubic centimeters of 5 per cent ammonium acetate solution were added and the liquid was titrated against standard uranium solution, taking the usual precautions. The magnesium was calculated in parts per million of water.

Sulphates.—The usual gravimetrical method was employed for this radicle, and the SO_4 calculated to parts per million of water.

Sodium and Potassium.—The filtrate from the sulphate determination was used for these elements. The solutions were made alkaline with ammonia and treated with ammonium carbonate and filtered. The filtrate was evaporated to dryness on the water bath, was heated slowly over a flame to expel the ammonium salts, and then was digested with a little water. The magnesium was precipitated by barium hydrate solution, the solutions were again filtered and the precipitates were well washed with hot water. The filtrate was heated and the barium and calcium were precipitated with ammonium carbonate, and were removed by filtration, after which the filtrate was evaporated to dryness and gently heated over the flame to expel the ammonium salts. The residue was treated with hot water and the above operations were repeated to remove any traces of barium and calcium. The solution was then filtered into a small platinum dish and evaporated to dryness and heated to near fusion and weighed. The alkaline chlorids in the dish were dissolved in water and filtered through an ashless filter paper, which was then washed, ignited in the platinum dish and weighed. The difference in weights was calculated to "sodium and potassium", the molecular weight fifty-eight being used for the material. This was calculated to parts per million of water.

Carbonate and Bicarbonate.—The determination of these radicles was made upon fifty cubic centimeters of the water, which usually was filtered. This water was titrated against M/50 potassium acid sulphate solution, using phenol phthalein as an indicator. The number of cubic centimeters of the potassium acid sulphate solution used multiplied by twenty-four equals the parts per million of the radicle CO_3. Methyl orange (two or three drops) were then added to the same solution and titration was continued. The total acid solution used, minus twice that required for the first end point equals that equivalent to the bicarbonates present. The latter figure multiplied by 24.4 equals parts per million of the radicle HCO_3.

Chlorine.—This radicle was determined by the usual volumetric method as recommended by Sutton in his handbook of volumetric analysis. One hundred cubic centimeters of water was usually concentrated to twenty-five to thirty cubic centimeters, when potassium chromate solution (two cc. of a five per cent solution) was added, and the solution was titrated against standard silver nitrate solution until a faint reddish tint was noted. The chlorine was computed to parts per million.

Nitrates.—The phenolsulphuric acid method was used in this determination. As most of the waters were more or less colored, the samples were first treated with alumina cream, shaken thoroughly, allowed to settle and fifty cubic centimeters of the clear liquor was used for this work. This was evaporated to dryness in a platinum dish on the water bath with a few drops of sodic carbonate solution. One cubic centimeter of phenolsulphuric acid was quickly and thoroughly incorporated into the residue in the dish, ten cubic centimeters of distilled water was added and the solution was thoroughly mixed. The solution was made alkaline with potassium hydrate solution, and then transferred to a 100 cc. Nessler tube and made up to the mark with distilled water. The yellow tint of the nitrates was compared with standards in similar Nessler tubes. The results were calculated to parts per million of water.

SOLUTIONS USED.

All solutions used in this work were made up according to the recommendations of the American Public Health Association in its bulletin on Standard Methods for the Examination of Water and Sewage, 1913.

Uses of Water.

In judging the values of any waters from their analyses, it is very necessary to consider to what purpose the water is to be used. Water is used essentially for steam making, starch, paper, laundry, etc., and the industries and the amount of the different ingredients determine its value for the particular industry. If the water contains a large amount of iron, it might render the water unfit for some industries, while in other work, the iron would have no serious effect. So with the other ingredients. Therefore, it is essential to consider all available sources and qualities of waters before deciding upon its application.

WATER FOR BOILER PURPOSES.

The chief use of water industrially is in the manufacture of steam and its value depends upon the amount and the chemical nature of the mineral matter dissolved or suspended in it. The main difficulties experienced in the boiler room from mineral contents of the waters are corrosion, scale and foaming.

Scale.—The formation of scale within a boiler is the deposition of the mineral matter upon the shell and tubes of the boiler. This deposition is caused by the water being heated under pressure and hence concentrated, whereby the mineral contents are thrown out of solution and are deposited upon the boiler as indicated above. This deposition causes all kinds of trouble as well as increased fuel consumption and repairs. If allowed to accumulate, disastrous results are liable to follow.

The scale consists practically of all the suspended matter, silica, iron, aluminum as oxides, calcium as carbonate or sulphate, and the magnesium as oxide or carbonate. The scale, therefore, varies in amount as the ingredients of the water vary, and varies in hardness and composition with the different conditions of steam pressure, type of boiler, etc. Hence, the value of a water for boiler use depends upon the quantity of scale produced, and the physical properties of said scale.

Corrosion.—This is caused chiefly by the action of acids dissolved in the water upon the boiler or boiler tubes. Free acid is sometimes found in water, especially in the region of coal mines, where the drainage from the mines is in many cases acid. Acid is also found sometimes in the wastes of factories along the streams. Hydrogen sulphide and carbon dioxide are corrosive in action.

Acids freed from their basic radicles, like iron, aluminum and magnesium, precipitated as hydrates and later possibly converted to oxide, are particularly corrosive. The acid radicles that were in equilibrium with these bases may do one or all of the following: They may pass into equilibrium with other bases, or they may decompose carbonates that have been precipitated to form scale or they may act upon the iron of the boiler or boiler tubes. If the acid exceeds the amount necessary to decompose the carbonate and bicarbonate then the boiler tubes or shell are attacked, with resulting pits or possibly leaks.

Remedies for Boiler Troubles.—The best way to obviate boiler troubles is to treat the water, in other words, purify it before it enters the boiler. This can be done in a number of different ways, but will not be considered in this article. When it is not possible to give such treatment, there are various other ways which can be cited. Blowing off the boiler occasionally is a good practical way of preventing foaming and also carries away considerable soft scale or sludge. Boiler compounds have been employed with some success, but it is advisable to use caution in their use, for the result may be the exact opposite of what is expected. It is sufficient to say that most of the boiler compounds upon the market depend largely upon the action of soda ash, oil or some vegetable extract, which makes them costly.

Their only functions are to prevent hard scale, and blowing off the boiler is necessary to prevent too large an accumulation of the soft sludge. It is far better to treat the water judiciously with known chemicals, than to add unknown boiler compound indiscriminately.

WATER FOR OTHER PURPOSES.

It is well known that various manufactured articles are more or less affected by the water used in their manufacture. In some industries, like starch, milk, canneries, creameries, slaughter houses, breweries, sugar works, tanneries, glue factories, soap factories, etc., water is a part of the final product or is essential to its manufacture; therefore, a supply free from color, odor, suspended matter, iron and bacteria is generally necessary. Water fit for drinking is necessary in industries where the final product is for food consumption, such as beverages or dairy and meat products, hence, the manufacturer is confronted with the problem of purifying his water and of deciding whether the cost of doing this is warranted by the increased value of his product.

Effect of Free Acids.—Free mineral acids, like sulphuric acid from coal mines, is particularly injurious to many industries. In cotton mills, bleacheries and dyeworks the acid decomposes the chemicals and streaks the fabric, and in some cases even rots it. The acid also is very corrosive to all metal work, such as screens, pipes, etc.

Effect of Color.—Color is due primarily to the solution of organic matter and articles washed, bleached or dyed in colored water are likely to show the effects. Highly colored waters can be used in dark dyed articles or wrapping papers, and the like, but for the whiter grades, it is essential to have a colorless or low color water.

Effect of Suspended Matter.—Suspended matter may consist of various particles of sewage, bits of leaves, sawdust, sand or clay, etc., and is particularly objectionable to industries in which water is used for washing or for food purposes. Suspended matter of vegetable origin is liable to decomposition and therefore is objectionable. For these reasons, water should be freed from suspended matter where it is to be used in laundries, bleacheries, dyeing, starch and sugar manufacture, breweries, etc.

Effect of Iron.—Iron is a particularly undesirable constituent of water, and even small quantities of it necessitate purification of the water for some industries. In all cleansing processes, precipitated iron is likely to cause rusty or dark spots. In goods containing tannin, iron will form greenish black substances that discolor the product. Therefore, the presence of even small amounts of iron necessitates purification before the water can be used in bleacheries, dyeworks, tanneries and the like, paper mills, where it is liable to cause a rusty spot in the fibre, and breweries, where it gives beer a bad color and sometimes a bad taste.

Effect of Calcium and Magnesium.—Calcium and magnesium have similar effects in the industries, particularly in any industry such as dyeing and paper making, where soap is used, for the calcium and magnesium are precipitated as insoluble compounds or soaps which instead of fixing themselves on the fibre, give a blotch or streak upon it. In the laundering industry they form insoluble soaps and therefore have no cleansing effect but are very likely to cause more or less trouble with the particular goods under treatment. In the soap industry, the calcium and magnesium form with the fatty acids curdy precipitates insoluble in water, and therefore of no value in the soap. It is also said that calcium and magnesium in water are a great source of trouble in distilleries because they tend to precipitate upon the grains, and therefore prevent the proper reaction from taking place during distillation.

Effect of Carbonates.—If hard waters high in carbonates and low in sulphates are boiled the bicarbonates are decomposed and the greater part of the calcium and magnesium are precipitated. For this very reason waters high in carbonates and low in sulphates are more desirable in industrial work than waters of low carbonates and high sulphates. It has been proven that waters high in carbonates are preferred in the manufacture of beer because they give a darker beer of more pronounced malt taste, while waters high in sulphates give a pale beer of a pronounced hop taste.

The Effect of Sulphates.—The effect of sulphates has been somewhat explained under "Effect of Carbonates". It is well known that sulphates interfere with the crystallization of sugar in sugar manufacture and tend to increase the amount of sugar retained in the mother liquor. Also sulphates are a source of trouble in the tanning industry, because they cause swelling of the hides.

Effect of Chlorides.—Waters very high in chlorides usually mean high alkaline waters. Such waters cannot be used in breweries or in canneries on account of the salty taste which the water would give the products. High chloride water is a detriment to the tanning industry, in that the hides are rendered soft and flabby. In the sugar industry the chlorides have a tendency to crystallize with the sugar, thereby affecting its quality. Chlorides also affect the germination of yeast, therefore, waters high in chlorides are a source of trouble to manufacturers of alcoholic beverages.

PURIFICATION OF WATERS.

Purification of water consists in the removal or reduction in the amount of those substances which render the water in the raw state unfit for the purpose desired. The main reasons why waters are purified are; (1) to render the water safe for domestic purposes; (2) to render the water fit for boiler purposes; and (3) to render the water free from those substances which are troublesome to the particular industry.

Waters for domestic purposes, or in other words, municipal supplies are required to be free from all disease bacteria, dirt, iron, odor, turbidity and taste; yet the elimination of the bacteria and suspended matter usually accomplishes the desired end. The usual method for this purification is slow sand filtration or rapid filtration after coagulation. The first method is quite slow, while the latter method is rapid and is accomplished by means of mechanical filters. The efficiency of either process is measured by the ratio of the amount of bacteria removed from the water to the amount of bacteria originally in the water. Under normal conditions this percentage is between 99. and 99.8 per cent.

For boiler purposes, it is essential to remove the scale-forming substances and to neutralize the corrosive constituents of the water. This is usually accomplished by one of the following methods—cold chemical precipitation, followed by sedimentation, and heat with or without the use of chemicals, followed by rapid filtration.

As already noted in this article, water for any particular industry requires special treatment, hence it is difficult to give any general method which is applicable to all; yet water properly prepared for municipal and boiler purposes, is generally fit for most industries, and it is usually more economical for small industries to purchase their water from the city than to maintain their own water and purification plant. It is not unusual for large industries to maintain their own water supply and purification plants. In some plants it is essential to have pure water, hence distilled water is manufactured and this is particularly essential in the manufacture of artificial ice and in breweries.

It is sometimes necessary to add copper sulphate, calcium hypochlorite, etc., to waters to kill organisms which may cause disease or give bad odors and tastes to the water. This method of purification requires great care, and must be done in such a way as to kill the bacteria and not render the water unfit for general purposes.

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

WATERLOO—CEDAR RIVER.

Date	No. 3 June 18, 1913	No. 14 July 2, 1913	No. 22 July 15, 1913	No. 33 Aug. 12, 1913	No. 42 Aug. 31. 1913
Turbidity	30.0	60.0	80 0	50.0	60
Coef. of Fineness	.66	.39	.30	6	21
Suspended Matter	20.0	23.4	24.0	30.0	30 8
Dissolved Solids	285.0	208.0	258.8	230.0	224 0
Dissolved SiO_2	9.6	15.4	7.4	6.8	7.6
Dissolved Fe	.16	.05	.1	1 1	.06
Dissolved Ca	56.	50.	59.0	48.6	37 6
Dissolved Mg	16.8	15.5	19 8	15.3	14.9
Dissolved SO_4	34.0	26.2	29.5	36.2	44 1
Dissolved Alkalies	32.8	6.8	21.2	8.7	17.6
Dissolved CO_2	9.8	5.9	12.7	11.7	11.6
Dissolved HCO_3	218 0	170.0	221.0	192.0	162 0
Dissolved Cl	5.7	1.4	3.4	4.0	6 0
Dissolved NO_3	.88	4.4	1 32	.35	2 64

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

CHARLES CITY—CEDAR RIVER.

Date	No. 4 June 18, 1913	No. 13 July 2, 1913	No. 21 July 15, 1913	No. 32 Aug. 12, 1913	No. 41 Aug. 31, 1913
Turbidity	40.0	70.0	15.0	80.	110.
Coef. of Fineness	.27	.6	.73	.21	.20
Suspended Matter	11.0	42.4	11.	17.0	22.4
Dissolved Solids	272.0	197.2	252.0	270.2	293.0
Dissolved SiO_2	22.8	16.0	14.8	10.0	16.4
Dissolved Fe	.06	.1	.08	.11	.12
Dissolved Ca	61.6	42.1	60.0	50.	64.4
Dissolved Mg	17.2	12.7	19 4	15.7	14.9
Dissolved SO_4	16.6	22.4	28.6	34.9	44.1
Dissolved Alkalies	9.6	15.8	17.4	23.6	15.1
Dissolved CO_2	13.6	....	9.8	19.5	5.8
Dissolved HCO_3	232.0	166.0	222.0	216.0	218.0
Dissolved Cl	11.3	3.5	7.0	11.0	8.0
Dissolved NO_3	.7	3.52	.88	.88	3.16

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

CEDAR RAPIDS—CEDAR RIVER.

Date	No. 5 June 19, 1913	No. 12 July 1 1913	No. 24 July 17, 1913	No. 34 Aug. 13, 1913	No. 44 Sept. 1, 1913
Turbidity	70.0	160.0	60.0	80.0	70.0
Coef. of Fineness	.45	.5	.93	.53	.47
Suspended Matter	30.8	66.0	56.0	42.6	33.0
Dissolved Solids	269.6	251.2	257.8	173.4	177.0
Dissolved SiO_2	17.2	11.8	20.0	6.6	5.0
Dissolved Fe	.24	....	.07	.13	.1
Dissolved Ca	56.8	51.3	44.4	28.8	27.2
Dissolved Mg	19.1	14.1	19.7	15.3	11.2
Dissolved SO_4	49.6	40.7	50.0	28.8	38.0
Dissolved Alkalies	21.2	13.2	20.4	9.3	14.7
Dissolved CO_2	9.8	13.7	....	....	7.8
Dissolved HCO_3	186.0	182.5	182.0	146.0	120.0
Dissolved Cl	4.9	6.2	3.8	5.0	6.4
Dissolved NO_3	.35	2.64	.18	.35	.88

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

FORT DODGE—DES MOINES RIVER.

Date	No. 7 June 23, 1913	No. 16 July 3, 1913	No. 27 July 29, 1913	No. 38 Aug. 22, 1913
Turbidity	60.	100.0	15.0	200.
Coef. of Fineness	.32	.48	1.13	.39
Suspended Matter	19.2	47.8	17.0	78.0
Dissolved Solids	484.8	368.0	417.6	416.8
Dissolved SiO_2	16.1	18.8	18.6	16.2
Dissolved Fe	.1	.3	.11	1.0
Dissolved Ca	86.1	73.	68.4	77.2
Dissolved Mg	22.4	23.	29.9	28.2
Dissolved SO_4	134.4	102.8	118.5	153.5
Dissolved Alkalies	41.2	19.0	23.6	17.0
Dissolved CO_2	34.1	12.7	....	5.8
Dissolved HCO_3	280.0	219.0	252.0	238.0
Dissolved Cl	4.4	3.0	12.4	11.6
Dissolved NO_3	1.06	2.64	.09	.35

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

DES MOINES—DES MOINES RIVER.

Date	No. 8 June 24, 1913	No. 17 July 9, 1913	No. 28 July 29, 1913	No. 37 Aug. 14, 1913	No. 43 Sept. 2, 1913
Turbidity	90.0	100.0	110.0	150.0	110.
Coef. of Fineness	.36	.44	.39	.21	.37
Suspended Matter	32.4	43.6	42.4	32.0	41.0
Dissolved Solids	425.6	370.2	427.4	422.0	387.0
Dissolved SiO_2	16.4	15.2	18.6	21.0	19.2
Dissolved Fe	.05	.5	.2	.16	.12
Dissolved Ca	73.7	65.8	82.0	72.8	60.8
Dissolved Mg	21.8	21.4	16.5	28.2	14.1
Dissolved SO_4	114.4	108.2	120.0	141.5	113.1
Dissolved Alkalies	42.5	26.4	26.0	21.9	19.3
Dissolved CO_2	13.3	5.9	9.8	....	7.8
Dissolved HCO_3	243.0	232.0	238.0	256.0	188.0
Dissolved Cl	5.4	4.8	7.2	7.4	5.0
Dissolved NO_3	.88	.35	.35	.35	2.2

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

OTTUMWA—DES MOINES RIVER.

Date	No. 9 June 24, 1913	No. 18 July 10, 1913	No. 29 July 30, 1913	No. 36 Aug. 14, 1913	No. 45 Sept. 2, 1913
Turbidity	2000.	80.0	120.0	160.0	320.
Coef. of Fineness	.408	.36	.35	.4	.40
Suspended Matter	816.6	28.8	42.4	65.0	96.2
Dissolved Solids	218.0	344.0	410.6	355.0	372.4
Dissolved SiO_2	18.0	10.2	16.6	11.0	12.0
Dissolved Fe	.28	.07	0.1	.06	.25
Dissolved Ca	55.8	63.7	72.4	64.0	67.2
Dissolved Mg	8.3	23.4	28.2	27.7	26.1
Dissolved SO_4	46.3	88.4	102.7	112.2	118.7
Dissolved Alkalies	15.5	17.8	26.3	18.7	17.6
Dissolved CO_2	....	....	....	13.7	....
Dissolved HCO_3	151.0	260.0	276.0	204.0	232.0
Dissolved Cl	4.4	5.8	10.2	8.0	6.8
Dissolved NO_3	4.4	.18	.35	.88	.88

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

MARSHALLTOWN—IOWA RIVER.

Date	No. 1 June 17. 1913	No. 10 July 1, 1913	No. 19 July 14, 1913	No. 25 July 28, 1913	No. 30 Aug. 11, 1913	No. 39 Aug. 30, 1913
Turbidity	70.	180.0	50.0	20.0	60.0	70.0
Coef. of Fineness	.95	.41	.55	.71	.51	.27
Suspended Matter	66.6	74.8	16.6	14.1	30.8	19.0
Dissolved Solids	392.0	338.8	302.4	332.2	286.8	307.8
Dissolved SiO_2	11.8	12.8	11.2	17.4	10.8	17.
Dissolved Fe	.13	.14	.13	.15	.12	.25
Dissolved Ca	57.3	68.5	67.8	62.8	53.20	60.
Dissolved Mg	27.0	27.4	20.3	26.7	22.60	24.5
Dissolved SO_4	47.2	41.8	49.5	42.8	45.80	48.0
Dissolved Alkalies	19.3	19.3	14.1	12.6	17.80	13.5
Dissolved CO_2	00.0	16.0	14.7	17.6	....	11.6
Dissolved HCO_3	263 0	291.0	254.0	268.0	236.0	246.0
Dissolved Cl	3.0	3.0	3.4	9.2	3.4	4.0
Dissolved NO_3	1.24	2.5	.34	.17	.53	3.52

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

Iowa Falls—Iowa River.

Date	No. 2 June 18, 1913	No. 15 July 3, 1913	No. 20 July 15, 1913	No. 26 July 29, 1913	No. 31 Aug. 12, 1913	No. 40 Aug. 31, 1913
Turbidity	200.0	180.0	180.0	200.0	170.0	240.0
Coef. of Fineness	.41	.35	.24	.46	.17	.24
Suspended Matter	82.0	62.6	44.2	21.0	29.4	58.0
Dissolved Solids	419.0	379.4	338.0	357.4	372.4	341.6
Dissolved SiO_2	24.0	28.2	20.2	14.0	21.4	23.0
Dissolved Fe	.3	.1	.15	.5	.2	.89
Dissolved Ca	93.0	85.3	67.6	70.8	71.6	70.
Dissolved Mg	14.0	27.4	25.8	30.8	23.0	23.3
Dissolved SO_4	51.0	52.0	53.8	66.8	54.6	67.6
Dissolved Alkalies	34.0	14.5	13.1	11.8	26.1	6.7
Dissolved CO_2	20.0	13.7	....	6.8	....	9.8
Dissolved HCO_3	301.0	309.0	314.0	296.0	324.0	254.0
Dissolved Cl	5.0	2.0	2.8	7.0	3.2	3.6
Dissolved NO_3	.12	1.3	.18	.35	.44	4.0

COMPOSITION OF RIVER WATER IN IOWA.

(Parts per million.)

Iowa City—Iowa River.

Date	No. 6 June 19, 1913	No. 11 July 1, 1913	No. 23 July 17, 1913	No. 35 Aug. 13, 1913	No. 43 Sept. 1, 1913
Turbidity	190.0	380.0	200.0	170.0	190.0
Coef. of Fineness	.37	.29	.21	.18	.24
Suspended Matter	71.2	109.0	42.2	47.0	46.
Dissolved Solids	315.0	329.0	256.0	269.0	269.
Dissolved SiO_2	11.6	15.2	15.6	7.2	23.
Dissolved Fe	.4	.1	.11	.2	.12
Dissolved Ca	77.4	74.3	43.2	57.6	59.2
Dissolved Mg	18.0	6.5	18.5	11.8	15.7
Dissolved SO_4	55.2	68.2	33.4	55.6	51.5
Dissolved Alkalies	26.4	23.4	12.0	20.4	5.2
Dissolved CO_2	12.3	8.2	....	8.9	5.9
Dissolved HCO_3	245.0	214.0	250.0	204.0	198.0
Dissolved Cl	6.8	6.4	5.2	5.2	6.0
Dissolved NO_3	.7	7.0	.18	.62	1.76

COMPOSITION OF RIVER WATERS IN 1912.

Place	Date	Sample Number	Direct from River or Filtered River Water	Turbidity	Suspended Matter	Dissolved Solids	Dissolved Si	Dissolved Fe	Dissolved Ca	Dissolved Mg	Dissolved SO_4	Dissolved Alkalies	Dissolved CO_2	Dissolved HCO_3	Dissolved Chlorine	Dissolved NO_3
Raccoon River—																
Des Moines........	6/25	H-3	Direct	220.	112.	428.	21.	4.	92.	22.	110.	21.	..	274.	4.2	41.0
Valley Junction...	6/25	H-5	Direct	385.	73.	460.	17.6	8.6	71.	22.	169.	1.0	..	236.	4.0	.04
West Ninth Street Bridge, Des Moines	7/22	H-19	Direct	3560.	602.	297.	10.0	1.4	54.	20.	94.	14.0	..	184.	11.0	0.5
Des Moines River—																
Des Moines........	7/22	H-18	Direct	430.	86.	249.	11.0	3.0	54.	17.	60.	17.0	..	103.	7.0	0.5
Harvey	7/23	H-20	Direct	490.	215.	320.	10.0	0.4	63.	19.	89.	12.0	..	198.	11.0	0.2
Keosauqua	7/23	H-21	Direct	720.	177.	353.	16.0	0.4	70.	24.	101.	8.0	..	218.	13.0	0.2
Ottumwa	7/23	H-22	Direct	625.	190.	335.	14.0	0.4	70.	21.	76.	3.0	..	212.	7.0	0.5
Emmetsburg	7/25	B-2	Direct	70.	29.	439.	4.0	.04	81.	32.	140.	17.0	..	248.	3.0	0.3
Fort Dodge	7/23	B-3	Direct	50.	20.	359.	7.0	.04	74.	23.	64.	11.0	..	126.	5.0	.4
Estherville	7/23	B-4	Direct	60.	22.	486.	5.0	.02	92.	32.	159.	16.0	12.	246.	9.0	.4
Boone	8/15	W-2	Direct	15.	49.	340.	10.0	.06	60.	25.	109.	21.0	..	220.	8.0	.06
Cedar River—																
Cedar Rapids	8/19	W-5	Direct	575.	191.	231.	6.	.8	85.	9.	55.	32.	..	162.	8.0	:3
Cedar Rapids	8/20	W-6	Filtered	5.	4.	276.	6.	.2	54.	21.	88.	8.	..	167.	6.0	2.0
Charles City.......	9/14	W-11	Direct	80.	25.	258.	8.	.06	58.	19.	24.	12.	21.	208.	6.0	.4
Iowa River—																
Iowa Falls........	9/15	W-12	Direct	140.	95.	306.	14.	.5	58.	23.	36.	16.	21.	235.	2.0	.5
Iowa City.........	8/19	W-4	Direct	340.	159.	275.	7.	.5	56.	23.	76.	9.	9.	199.	7.0	.3
Iowa City.........	8/18	W-3	Filtered	5.	7.	324.	8.	1.0	65.	26.	61.	14.0	..	288.	7.0	.5

THE IOWAN DRIFT, A REVIEW OF THE EVIDENCES OF THE IOWAN STAGE OF GLACIATION

BY

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PREPARED IN COOPERATION WITH THE UNITED STATES GEOLOGICAL SURVEY

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Introduction

CHARACTER OF THE INVESTIGATION AND GENERAL RESULTS

For many years northeastern Iowa has been a region of great interest to students of Pleistocene geology and many papers have been published treating of its various features. Differentiation of the deposits as the product of several distinct ice invasions may be said to have begun with the tracing of the limits of the drift of the Des Moines lobe of the last ice sheet as distinguished from older drift in the area outside. Later the United States Geological Survey published W J McGee's paper on the Pleistocene of northeastern Iowa,[1] in which he showed that there were two drift sheets in this part of the state which were older than the drift of the Des Moines lobe. Still later the Iowa Geological Survey, with the late Dr. Samuel Calvin at its head, reached the conclusion that instead of two drift sheets there were really three in northeastern Iowa, each the product of a distinct ice advance prior to the incursion of the Des Moines lobe. The progress of the investigations necessitated certain changes in the classification and the shifting of names to designate the deposits. It is not necessary to consider in this place these changes in the nomenclature nor the merits of such adjustments as were made. The elaboration of the remarkable Pleistocene classification that resulted from these and correlated studies called for close scrutiny of the evidence and almost inevitably differences of opinion arose concerning some of its features. Skepticism centered principally on the Iowan drift, said to be the product of the fourth great glacier which had invaded the area of the state or the third which spread over

[1]McGee, W J, The Pleistocene of northeastern Iowa: U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, pp. 189-577, 1891.

northeastern Iowa. This skepticism arose very largely because of difference of opinion as to the interpretation to be given certain of the phenomena observed. This was expressed particularly in several papers published by Frank Leverett of the United States Geological Survey. In defense of the Iowan drift a number of papers were published by Doctor Calvin. The discussion had to do principally with two questions: (1) Is there really in northeastern Iowa a drift sheet of pre-Wisconsin age distinct from, and younger than, the Kansan drift? and (2) If so, is it to be correlated with the Illinoian drift sheet (of Leverett), or was it the product of a distinctly later ice invasion? The matter was still in question at the time of Doctor Calvin's death in 1911. There being a desire for a review of the evidence bearing on the Iowan problem, Doctor Calvin's successor, the present State Geologist, Dr. George F. Kay, finally requested the United States Geological Survey to cooperate with the Iowa Survey in an investigation of the matter. An agreement was reached and the senior author of this report was assigned to this work by the Federal Survey with Morris M. Leighton of the Iowa Survey as assistant.

The summer seasons of 1914 and 1915 were spent on the field investigations besides careful study of the published and unpublished material in the office. It is a pleasure to report that the conclusion has been reached that there is what seems to the writers to be good evidence of the presence of a post-Kansan drift sheet in northeastern Iowa and that this drift appears to be older than the Wisconsin and younger than the Illinoian drift. The writers are, therefore, in the main in agreement with the late State Geologist, Dr. Samuel Calvin, in regard to the Iowan drift. There is, therefore, warrant for continued use of Iowan drift and Iowan stage of glaciation as major subdivisions of the Pleistocene classification. This classification is as follows:

PLEISTOCENE EPOCH.

9. Wisconsin stage of glaciation (of Chamberlin)
    8. Peorian stage of deglaciation (of Leverett)
7. Iowan stage of glaciation (of Iowa geologists)
    6. Sangamon stage of deglaciation (of Leverett)

5. Illinoian stage of glaciation (of Leverett)
    4. Yarmouth stage of deglaciation (of Leverett)
3. Kansan stage of glaciation (of Iowa geologists)
    2. Aftonian stage of deglaciation (of Chamberlin)
1. Nebraskan stage of glaciation (of Iowa geologists) (pre-Kansan of Chamberlin) (Jerseyan of eastern United States)

These subdivisions of Pleistocene time are represented in Iowa by the following:

PLEISTOCENE DEPOSITS.

9. Wisconsin drift (of the Des Moines lobe)
8. (b) Peorian soil and weathered zone (of Leverett) at top of loess and beneath Wisconsin drift
    (a) Main deposit of loess[2]
7. Iowan drift (of Iowa geologists)
    6. Sangamon soil, vegetal deposits, and weathered zone (of Leverett) (including super-Illinoian "gumbo," or "gumbotil" of Kay) at top of Illinoian drift and beneath loess
    5. Illinoian drift (of Leverett)
4. Yarmouth soil, vegetal deposits, and weathered zone (of Leverett) (including super-Kansan "gumbo," or "gumbotil" of Kay[3]) at top of the Kansan drift; also Buchanan gravel (of Iowa geologists) beneath Iowan drift and loess
3. Kansan drift (of Iowa geologists)
2. Aftonian gravels, vegetal deposits, soil and weathered zone (of Chamberlin) (including super-Nebraskan "gumbo" or "gumbotil" of Kay) at top of Nebraskan drift
1. Nebraskan drift (of Iowa geologists) (pre-Kansan or sub-Aftonian of Chamberlin)

In the course of the field work about 175 traverses were made in and adjacent to the Iowan drift area and a large number of exposures were carefully examined. Fortunately, many new cuts were available as the result of recent grading on the wagon roads and electric and steam railways. In addition about 250

[2]Local deposits of loess and of laminated silts occur on the Wisconsin and older drift sheets.

[3]Kay, Geo. F., Gumbotil, a new term in Pleistocene geology: Science, new ser., Vol. XLIV, pp. 637-638, 1916.

borings were made with a 2-inch auger 8 feet in length. The auger was used principally where exposures were not available, particularly on the typical Iowan plains and other uplands Samples obtained thereby were carefully examined for determination of the character, the depth of leaching and degree of oxidation of the superficial parts of the drift. Not much attention was given to the collection of well data, reliance being placed on the statements in the reports of the Iowa Survey for the thickness of the drift.

Many examinations for purposes of comparison were made outside the Iowan drift area in the Kansan and Illinoian drift areas in Iowa and by Mr. Alden on the Illinoian drift in Illinois. Besides these, a number of reconnaissance trips were made by Mr. Alden in the area outside the Wisconsin terminal moraine in southeastern Minnesota. Some of these were in company with one or two of the following gentlemen, Frank Leverett, F. W. Sardeson, and Samuel Weidman. The writers are especially indebted to T. C. Chamberlin, R. D. Salisbury, George F. Kay and Frank Leverett. Conferences were had also with Wm. H. Norton, R. T. Chamberlin, J. E. Carman, A. C. Trowbridge, A. O. Thomas and J. A. Williams.

In connection with this study the writers were fortunate in having access to the field notes of the late Doctor Calvin, to an unpublished manuscript by Mr. Leverett, to some notes by T. C. Chamberlin on field conferences in Wisconsin, Minnesota, and Iowa, and to field notes of R. T. Chamberlin on his studies in 1906 and 1907 of the drift in southern and eastern Iowa, southeastern Minnesota and northwestern Wisconsin, for the United States Geological Survey. In the course of these latter studies R. T. Chamberlin made many estimates of the lithologic composition of the several drift sheets by the counting and sorting of pebbles. Through his kindness the present writers are permitted to include in this report the results of these estimates together with the results of similar estimates made by themselves. They are compiled in the tables presented in Appendix A.

The writers are indebted to R. D. Salisbury for examination and criticism of a preliminary draft of the manuscript, and Frank Leverett and F. W. Sardeson also very kindly examined and criticised the manuscript of this report. They are, however, in no way responsible for the interpretations presented. To all these gentlemen the writers wish to express their appreciation.

As stated above, the investigation has yielded what seems to the writers to be good evidence of a post-Illinoian and pre-Wisconsin glaciation of northeastern Iowa. There may, of course, be room for differences of opinion as to some of the interpretations. Were the phenomena entirely clear and decisive the question would not so long have remained open. The evidence is not, however, like a chain whose maximum strength is that of the weakest link, but may rather be likened to a rope composed of strands none of which alone may be able to support the burden but whose combined pull in the same direction brings conviction.

Inasmuch as this paper is intended primarily as a review of the evidence rather than as an argument in favor of the Iowan stage of glaciation the effort has been made to bring together about all the available data bearing on the question. Some of the less important details have been put in the appendices. Some of these have little value as evidence and some may not appear to be pertinent. Quite a number of different persons have studied the Pleistocene geology of this region and numerous supposed occurrences of Iowan drift have been cited, so that it has seemed best to take cognizance of data published even though some of it may not now appear very important.

It has been thought not to be necessary to present in this paper a detailed discussion of the history and development of the classification of the Pleistocene deposits of Iowa. There are in the text numerous references to earlier publications of various writers, but no bibliography or review of papers treating of the Iowan drift is presented. For reference to these papers readers should consult the annotated bibliography of Iowa geology and mining by Charles Keyes, volume XXII, Iowa Geological Survey (1912) or the several bibliographies of North American geology published by the United States Geological Survey.

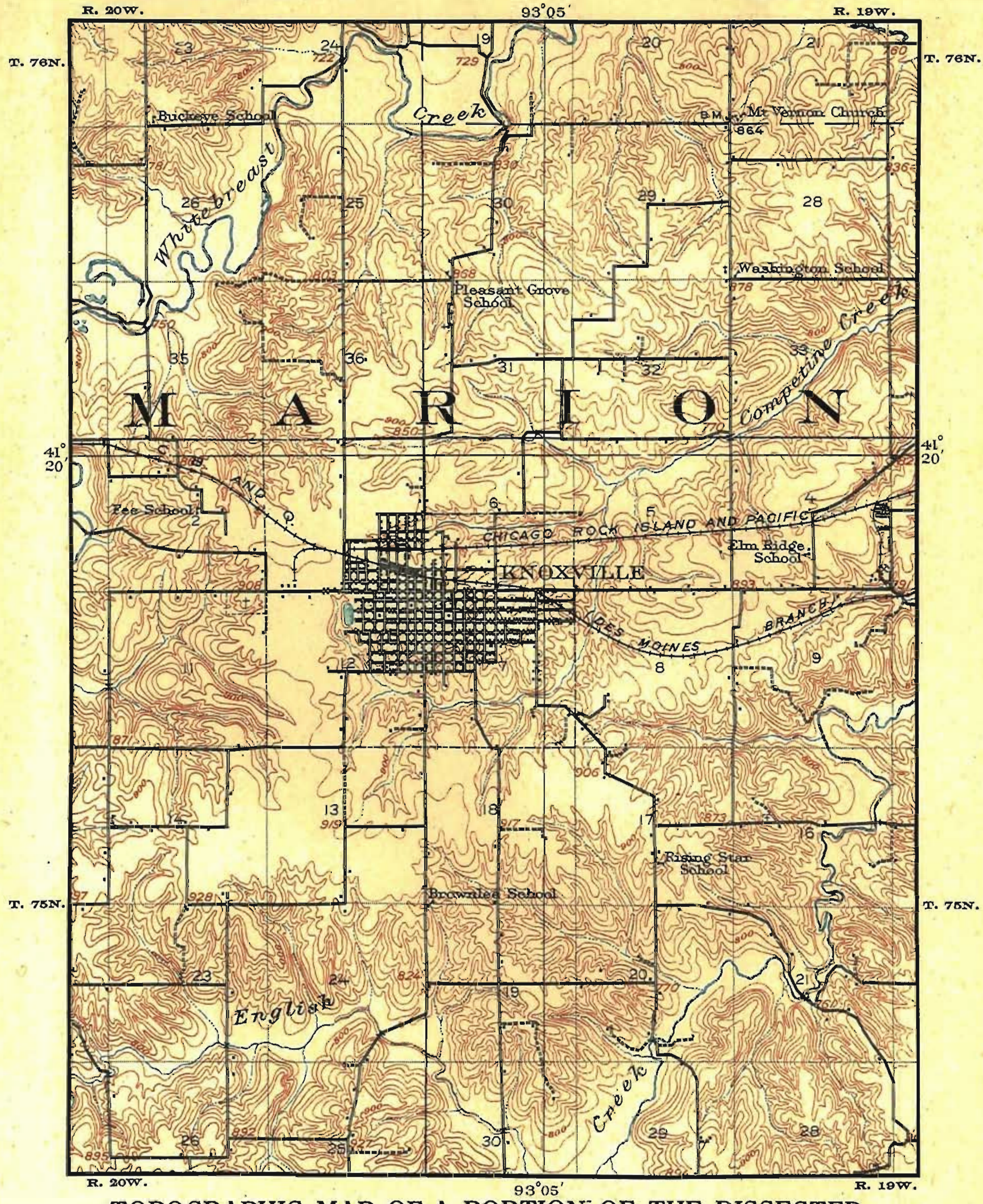
CHAPTER 1

THE IOWAN DRIFT.

DISTRIBUTION AND CONFIGURATION IN IOWA.

Area.—The evidence reviewed in this paper seems to the writers to indicate that a post-Kansan glaciation (pre-Wisconsin and post-Illinoian) extended over that part of northeastern Iowa lying between the east boundary of the Wisconsin drift on the west and the belt of thin drift bordering the Driftless Area on the east. The drift deposited at this stage is the Iowan drift. The Iowan ice sheet may also have covered part of southeastern Minnesota, but the writers have not themselves examined enough of that area to warrant its discussion in this paper. The Iowan drift in Iowa lies principally in the basins of Cedar and Wapsipinicon rivers. The eastern part is drained by the headwaters of Upper Iowa, Turkey, Volga, and Maquoketa rivers and some of the southern part of the area drains to Iowa river. This area, more than 9,000 square miles, is larger than Massachusetts and about equal to New Hampshire or Vermont, and somewhat less than Maryland.

Topography.—Comparisons of surficial configuration and of the degree of modification of the drift by erosion have generally been among the criteria for discrimination of the relative ages of different drift sheets so that this review may well begin with a study of the topography. The sort of topography generally characteristic of this part of northeastern Iowa is somewhat peculiar and it is recognized that there may be considerable difference of opinion as to its interpretation. The influence of certain factors such as of slope, of material and of vegetal cover, and of earlier climatic conditions, are not readily evaluated and their discussion is not attempted in this connection. Such study of this and adjacent areas as the writers have made in the course of this investigation seems to them, however, to show topographic differences which, taken in connection with the other data here presented, are significant of differences in the age of the glacial drift.



TOPOGRAPHIC MAP OF A PORTION OF THE DISSECTED KANSAN TILL PLAIN IN MARION COUNTY, IOWA

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 Miles

Contour interval 20 feet.

Datum is mean sea level.

The topography of the Iowan area is, in general, what the writers would call a mantled, mature-erosion type. There is not, with some exceptions, the depositional type seen in the Wisconsin drift area where the surface configuration is largely, if not primarily, due to the irregular deposition of the drift, either of the undulating ground moraine type or the sag-and-swell, or knob-and-kettle morainal type, with the nearly total obliteration of the configuration of the underlying surface. In the Iowan area, though it is not generally dissected by sharp-cut, eroded valleys, there are yet present nearly everywhere the main features of maturely branching stream-erosion systems. The valleys divide and sub-divide in dendritic fashion and their branches reach most parts of the area. Even the more nearly flat and less dissected parts show this drainage pattern.

There is a difference, however, between this topography and that of most of those parts of the Kansan drift area known to the writers. In the latter there is not only deep dissection but the ramifications of the branches are developed in minute detail down to ravines and gullies trenching the slopes at intervals of a few rods. Convex curves prevail on the slopes and more or less sharply cut, V-shaped, cross-profiles predominate except in the broader, flat-bottomed valleys.

The topography of the Kansan drift, which has been developed by long erosion of a nearly flat drift plain, is well illustrated by the contours on Plate I, reproduced from a part of the Knoxville topographic sheet. This is one of the newly surveyed areas and the dissected topography is about as accurately reproduced as the scale of the map permits. There is, however, even more detailed dissection of slopes than can be shown on this scale. There is a relief of 100 to 200 feet in this area and only narrow remnants of the original plain remain as uplands; and, as seen in the field, it would be noted that even much of the upland tracts is scarred by the tips of the erosion lines.

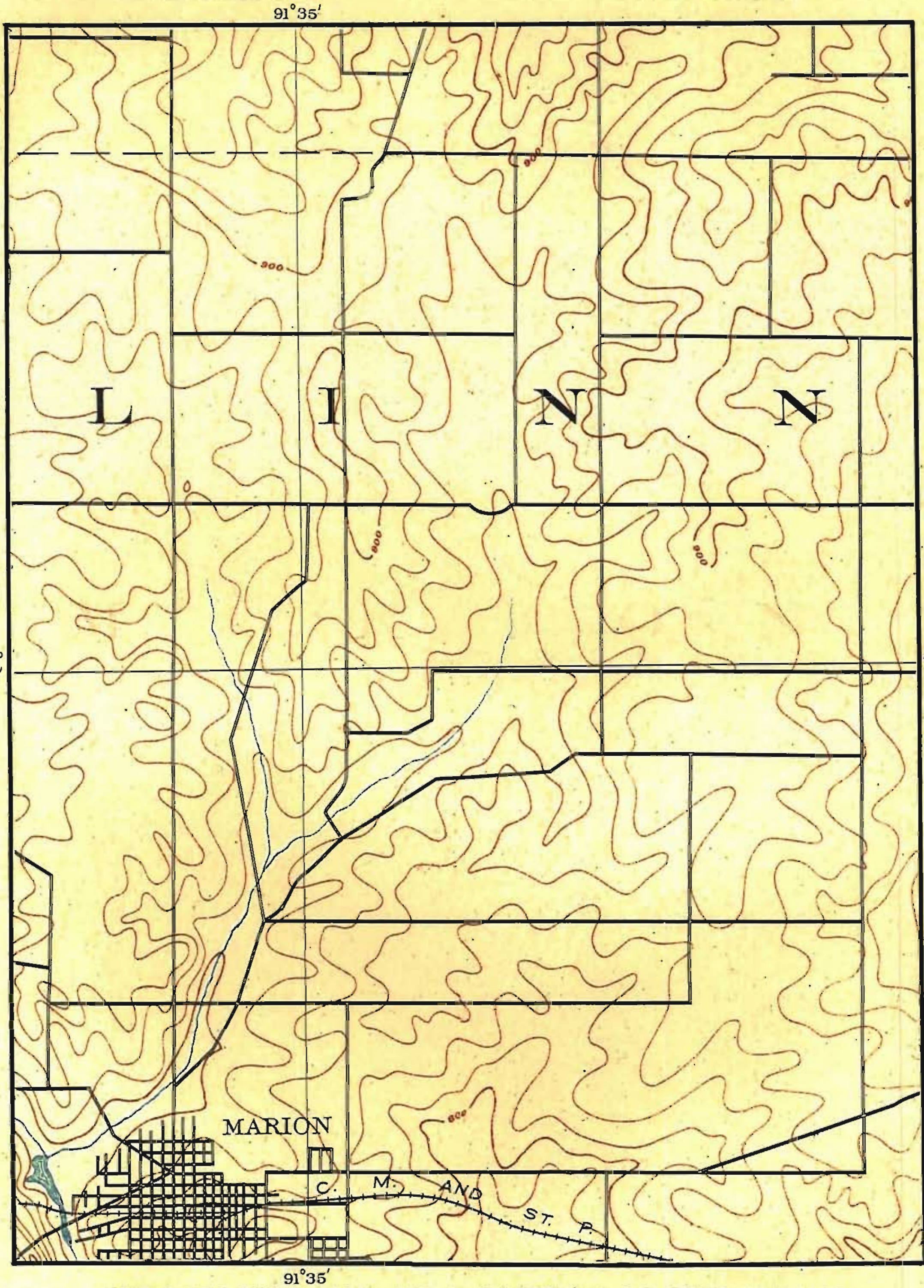
This type of topography and degree of dissection is characteristic of nearly all parts of the Kansan drift area which have been seen by the writers. The same is illustrated by Plates III and IV.

In the Iowan drift area, while the main features of the dendritic branching systems are present the minor details are more generally lacking. V-shaped cross- profiles are rarely seen. The side slopes are long and of low grade and pass at the bottom into concave curves. The minor valleys are thus broad open swales which fade out indefinitely into nearly flat, interstream, upland areas. Though these valleys are quite capacious in their lower parts, as the relief ranges from 30 to 150 feet, the slopes are smooth and uncut, or very little cut, by ravines and gullies. One looks in vain, in most places, for the smaller branches and twigs of the dendritic system. The present streams do not appear to have been the sole agents in giving the valleys their present contours. These streams meander in shallow trenches cut in broad bottoms of the swales. The waters from the valley slopes appear to run off in sheets, so to speak, rather than by gathering into converging gullies and ravines. One looks directly down open troughs, broad and relatively shallow, though often of considerable actual depth, and sees the slopes in large measure unscarred by erosion lines and not made irregular by projecting spurs.

This type of topography is fairly well illustrated in Plate II which is a reproduction of parts of the Marion and Anamosa topographic sheets on the same scale as Plate I. This shows a part of the typical Iowan drift plain. It should be noted that this is from the older and less accurate of the topographic sheets. Parts of this older set of maps which cover maturely dissected Kansan drift areas to the east of the Iowan drift area and to the south in Cedar, Johnson, and Iowa counties, do not represent the dissected topography there with anything like the accuracy of detail found on the newer maps. This is true also of those parts of the older maps covering Illinoian drift areas in Scott and Muscatine counties, so that comparisons should not be made of the contouring of the typical Iowan topography on these old maps with that of the Kansan or Illinoian topography on the same set of maps. On the other hand, critical examination in the field shows that the typical Iowan topography, such as that of the part of Linn county shown in Plate II is fairly well represented by the apparently

BASE FROM U. S. G. S. TOPOGRAPHIC MAP
(MARION SHEET, IOWA)

IOWA GEOLOGICAL SURVEY
PLATE II



TOPOGRAPHIC MAP OF A PORTION OF THE IOWAN DRIFT PLAIN IN LINN COUNTY, IOWA

Scale $\frac{1}{62,500}$

0 ½ 1 2 3 Miles

Contour Interval 20 feet

Datum is mean Sea level.

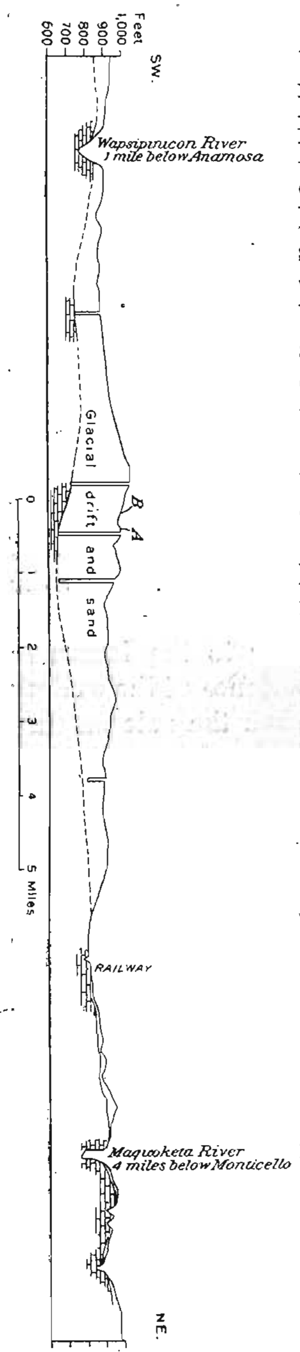
View in northeastern Washington County, Iowa, showing mature erosion of the Kansan drift plain. Relief 100 to 150 feet.

View in Union County, southeast of Afton, Iowa, showing branching of erosion lines on the dissected Kansan drift plain.

generalized contours used. The contour lines which mark the reëntrants of the long undissected slopes of the swales should be open, rounded curves, such as are shown, rather than the sharply angular V-shaped reëntrants required to represent the dissected slopes of the Kansan and Illinoian drift areas.

Comparison of Plate II with Plate I shows the character of the Iowan drift plain as here represented to be distinctly different from the much dissected topography of the Kansan drift. The careful and critical observer who has seen thousands of square miles of this type of topography is impressed with the idea that it must be the result of some different geologic condition from that which produced so much of the Kansan topography. The reader should bear in mind that, while there are limited tracts in the midst of the Iowan area and especially in the border belts where there is considerably sharper relief and more dissection, the type here shown is characteristic of thousands of square miles of the Iowan drift area. It is the prevailing type of the Iowan drift topography. There are also some limited tracts with topography similar to the Iowan in the Kansan drift area, but so far as the experience of the writers goes it is distinctly the exception rather than the rule on that drift.

The impression gained by the writers from a careful study of this topography is that a dendritic-branching system had developed to maturity throughout the region by erosion, but that it was later masked in the Iowan drift area as though overridden by an ice sheet which left a relatively thin mantle of drift thereon, obliterating the minor branches of the drainage systems but leaving the main valleys and major branches only partly filled and that the amount of erosion which has occurred since the disappearance of the last ice sheet has been relatively insignificant. The small amount of this erosion as compared with that in the Kansan area seems to the writers to indicate that the time since the disappearance of the ice from the Iowan drift area could not have been nearly so long as post-Kansan time. They therefore regard the topographic character of the Iowan area as a whole as one of the evidences of a post-Kansan glaciation of this area.



Unfortunately, topographic survey of the whole area of the Iowan drift has not been made, though considerable areas farther north than that shown on Plate II are shown in a smaller scale (1:125000) on the Oelwein, Elkader, Winthrop, and Farley sheets. Topography of this smooth-mantled type does not lend itself well to illustration by photos or sketches because of the lack of dissection and low angles of slope. Certain of these are, however, shown in Plates V and VI, where they are contrasted with views of areas of similar maximum topographic relief in the Kansan area. These views are not exceptional but representative in character.

Interpretation of the Iowan topography, however, requires something more than mere casual inspection. It may be asked to what degree this mantled appearance of the topography in the Iowan drift area is due to the work of streams having been retarded by rock cutting as compared with the streams outside this area. Study by earlier students, by members of the Iowa Geological Survey, who prepared the reports on the several counties, and by the present writers shows that there has been considerable shifting of the drainage lines as the result of glaciation of the area. It is not now known how much of this was due to the earliest, or Nebraskan, ice sheet, and how much to the Kansan glaciation. Records of wells show thicknesses of drift in many counties to vary from a few inches to 200 or 300 feet, and some thicknesses of nearly 400 feet of unconsolidated deposits (mostly drift) are reported. In some places ancient valleys deeply buried have been definitely located. One of these, which may for convenience be referred to as the ancient valley of Wapsipinicon river, is shown in cross profile (figure 1).

Fig. 1.—Northeast-southwest section near Anamosa and Monticello showing relations of the present gorges of Wapsipinicon and Maquoketa rivers to an intervening, deeply buried river valley.

A

B

Compared topographies of the typical Iowan drift plain (A, south of Waterloo, Black Hawk County, Iowa) and the dissected Kansan drift plain (E. northwest of Oxford Junction, Jones County, Iowa.

The relations in the case of this stream and of some others seem to indicate that the relocation occurred as the Kansan ice sheet melted away, leaving former valleys blocked. Post-Kansan time has clearly been long, for the streams of southern Iowa have accomplished a great deal of dissection of that area. In many places the present topography of the Kansan area has been carved wholly in drift. In many other places, however, the streams after eroding the drift have cut deeply into, and removed large amounts of the older rock.

The rock underlying the Kansan drift area is largely Carboniferous shale and sandstone, but considerable limestone has also been encountered, especially in the lower courses of the rivers. In the Iowan area the drift is underlain chiefly by Silurian and Devonian limestones. The shales of southern Iowa may perhaps not have retarded erosion in that region as much as did the limestones in northeastern Iowa, but it does not seem probable that the greater dissection of the Kansan drift areas can be accounted for on this basis alone. In the belt of older drift between Mississippi river and what is mapped as the approximate east boundary of the Iowan drift, Maquoketa, Wapsipinicon, and Cedar rivers have cut gorges in the Niagaran limestone in Delaware, Jones, Jackson, Cedar, and Johnson counties apparently in post-Kansan time. The depth of cutting in rock ranges from 50 feet or less to about 125 feet. These gorges head back some distance into the Iowan drift area. Closely bordering these gorges on either side are sharply dissected tracts, but the tributaries are in general short and the lateral gorges soon head at rock sills in the lower parts of the broad open swales. This latter is true of the headwaters of the Volga, Turkey, and Upper Iowa rivers also.[4] This gorge-cutting must have had a considerable retarding effect on the work of the streams, but even so it is doubtful if the lack of dissection in the upper stream courses in the Iowan drift area can be accounted for by this retardation.

[4]In studying the sharply dissected topography in these areas, as shown on the topographic maps, some allowance must be made for the piling up on hills and sharpening of slopes by deposition of the loess subsequent to the Iowan stage of glaciation in the wooded belts bordering these streams. It is not so much a case of the streams leaving the interstream plain tracts for the hills, as described by McGee, as it is of the building up of hills of eolian deposits bordering the streams where the brush and trees so retarded the winds as to cause deposition of the dust swept off the prairies.

Owing to the close similarity in composition of the Iowan and Kansan drift sheets, as shown in a later connection, the approximate limits of the Iowan glaciation are necessarily largely determined on the basis of topography. The boundary has in general been placed where the smooth swale topography on the one hand gives place to the sharply dissected topography on the other. In the study in the field it was found that the eastern boundary as mapped by the Iowa Survey in any given valley, such for instance as that crossing Lime creek west of Hopkinton in southern Delaware county, had been placed at the point where the stream ceases meandering from side to side in the bottom of a broad open swale and begins cutting sharply downward into the Niagaran limestone. Below this point the stream flows in a constricted gorge whose sides are picturesque castellated cliffs of limestone, in places nearly 100 feet in height. The contrast is very striking and questions at once arise in the mind of the critical observer, "Do the broad, open swales forming the upper parts of valleys such as Lime creek, with their long, smooth undissected slopes, represent a young topography due to mantling by a post-Kansan drift sheet, or, is it in reality an old erosion topography in an area which has been rejuvenated and where the newer cycle represented by the gorge cutting has as yet advanced only so far up stream as the present topography indicates?"

While no satisfactory answer to this question was found on the basis of topographic configuration alone, there are several considerations which seem to the writers to indicate that there has really been mantling of a maturely eroded topography by a post-Kansan drift sheet in the area mapped as Iowan drift.

It is true that the gorge-cutting represents a new cycle of erosion (post-Kansan probably) in each such valley and the gorge-cutting has progressed only to a point where the stream is now on rock in the bottom of the swale. If, however, the swale is simply a mature topography developed on the Kansan drift by erosion alone and not mantled by a later drift, the long, low slopes would seem to represent an older stage of erosion than that reached lower down in the valley. On this basis, considering the Iowan area as a whole as compared with the Kansan area to the south, we would be led to conclude that the heads of the tributaries of the upper Mississippi basin had reached a more advanced stage of erosion than the tributaries of the same system farther south. This is in itself improbable. One might suppose that the rock exposed in the lower parts of the swales retarded dissection in the upper parts, yet the angles of the side slopes range from 2° to 8°, quite adequate for dissection if the valleys are old enough. In fact, it is surprising that they have not been cut by ravines since the Iowan ice disappeared. This may, indeed, afford ground for an opinion that some unknown factors are involved. One might also suppose that the drift, being more readily eroded than the limestone, would permit a mature stage of erosion to be reached in the drift of the upper part of the valley while the stream was yet cutting the constricted gorge in limestone in the lower part. It is to be noted, however, that the same relations of drift and limestone occur in the Kansan area to the south, yet there is, in general, so far as the writers have seen, no such combination of broad swales and low slopes on the upper stream reaches with sharp gorge-cutting lower down. As shown in Plates V, B and VI, B and as described above, the heads of the streams in the Kansan area are minutely-branching, sharply-cut, V-shaped ravines scoring the slopes at frequent intervals. The smooth swale topography so prevalent in the Iowan area seems to the writers to correspond very closely to what one would expect if a maturely dissected area were overridden by a re-advance of the ice and left mantled with a drift sheet of moderate thickness. Besides the definite evidence of the presence of a post-Kansan drift sheet it is shown in a later connection that, subsequent to the cutting of the gorges, gravels were washed into and through them and deposited. These gravels, which may be regarded as outwash from the Iowan ice sheet, have since been largely removed by erosion so that in places only remnants are found as terraces bordering the streams. The topographic condition of the Iowan area taken in connection with the direct evidence, presented later, of the presence of a thin drift sheet apparently of post-Kansan age and of outwash gravels to be correlated therewith, seems to the writers to make the case for the Iowan stage of glaciation fairly strong. The only other alternative seems to be that in their study of the topography some very important factor has been wholly left out of the consideration. It is not clear, however, that this is the case.

The occurrence of broad interstream areas which seem to have been covered by the Iowan ice sheet between the dissected belts bordering parts of Maquoketa, Wapsipinicon, and Cedar rivers leads to the inference that the Iowan ice really extended into the gorges, but that the ready avenues of escape for the glacial water resulted in most of the somewhat meager drift being swept down the valleys by the streams and in such as remained being left mostly as waterlaid sand and gravel. The lobate margin of the Iowan drift as mapped by Doctor Calvin and his associates gives to the reader the impression that the margin of the ice was actually similarly lobate at its maximum extension. It seems impossible, however, to think that the ice occupied the interstream uplands and did not extend down into the valleys which were in reality considerably lower, especially before the bordering loess hills were deposited. The writers have not made careful and detailed search of these valleys for remnants of the Iowan drift, but it seems necessary to conclude that the ice really lay in these valleys and thus a generalized boundary of the area covered by the Iowan ice sheet if it includes most of the lobate drift tracts which have been mapped, should extend across the intervening valleys with their dissected border belts. This is discussed in a subsequent connection (see Chapter VIII).

While the prevalent topographic character of the Iowan drift area is such as appears to have resulted from the mantling of a maturely developed, post-Kansan, erosional topography, there are exceptional areas where there is considerable sharp dissection and where the topography appears not to have been mantled. Reference has already been made to the principal areas of this kind along Maquoketa, Wapsipinicon, Cedar, and Iowa rivers. There is an isolated tract of this sort on the Maquoketa in the northwestern part of Delaware county, north of Dundee. The stream here flows through a picturesque wind-

A

B

Compared topographies of the typical Iowan drift plain (A, near Van Horn, Benton County, Iowa) and the dissected Kansan drift plain (B. west of Washington, Iowa).

ing gorge 50 to 150 feet in depth cut in the Niagaran limestone. On the melting of the ice sheet the stream was superimposed on a buried ridge of limestone. The subsequent work of the stream has developed the gorge. If the shifting was the work of the Kansan ice it seems necessary to suppose that the Iowan ice filled the gorge, but did not leave it buried in drift. On the other hand, it may be the gorge is of post-Iowan age, but this seems doubtful. A similar rock gorge is traversed by Cedar river at and above Osage.

Some loess-covered hilly tracts have been shown on the maps of the Iowa Survey as loess-covered Kansan drift. None of these areas is so high that it can be supposed that the Iowan ice did not cover it. It is hardly possible to conceive of an ice sheet competent to extend 150 miles or more southeastward in Iowa and to spread over an area of 9,000 square miles which was so thin as not to cover hills 100 feet or less in height. On the other hand, the load of drift carried by this ice was probably not very great and though covered by ice the hills may well have been unmantled or thinly mantled with Iowan drift, as was clearly the case in some other places. The steep slopes of these hilly tracts would favor erosion and the subsequent removal of thin drift. Moreover, their mantle of loess does not everywhere permit a determination of just what drift is present. Such tracts occur in Mitchell, Butler, Bremer, Black Hawk, Benton, and Linn counties. An exposure on one such hilly tract southeast of Hampton showed two feet of till, presumably Iowan, overlying much weathered drift or "gumbo," probably Kansan.

CHAPTER II

THE UPPERMOST TILL OF THE IOWAN AREA.

If the topographic configuration of the Iowan drift area is the result of post-Kansan glaciation and the deposition of a mantle of till on the dissected surface of the Kansan, it is to be expected that the uppermost drift of the Iowan area would show less modification by weathering than that of the parts of the Kansan drift area immediately adjacent. Conversely, if the drift generally exposed at the surface throughout the Iowan area shows on the whole less modification by weathering than does that of the Kansan area, it may be regarded as one evidence of post-Kansan glaciation of the area.

It may be contended that, unless the Iowa drift has distinctive lithologic or other characters by which it can be identified in every exposure (and unfortunately it has not), or unless it is everywhere distinctly separated from the underlying drift by a soil or weathered zone (which, of course, is not the case with any drift sheet), it is not permissible to infer that the uppermost drift at all, or even most, places in the area is the latest drift of the area. Thus any generalized statement of the character of the uppermost drift of the Iowan area might be said to be merely a description of the upper part of the Kansan drift, which is believed to be the main drift sheet in northeastern Iowa, or be a combination of data from exposures, some of them in Iowan drift and some of them in Kansan, and so not be really representative.

One familiar with the usual conditions of exposure of glacial deposits and knowing how far short of what are theoretically desirable for the proper discrimination of different drift sheets are these conditions must admit the justice of such statements. These limitations apply, however, in all drift areas and are not confined to the Iowan drift area. There are places in the Iowan area where the total of all drift deposits remaining is very small, in spots nothing at all, yet the writers are quite firmly of the opinion that an ice sheet of sufficient volume to spread so far south and cover 9,000 square miles in northeastern Iowa could not have failed to transport a considerable amount of drift and to have left a till sheet which was composed of more than patches of material derived from the deeply weathered upper part of the Kansan drift. There should be a till sheet of at least moderate thickness spread generally over the area though perhaps locally very thin or even absent in spots. If the topographic configuration is due to mantling of a dissected Kansan topography, as the writers believe it to be, there must have been enough glacial abrasion and deposition of drift to produce the mantling. It is, therefore, fair to expect, if a large number of exposures are examined and if a large number of borings are made, well distributed over the smoothly mantled area, that a compilation of the data will give a fairly good idea of the general character of the latest drift of the area, and of the amount of its modification by weathering.

Scores of exposures throughout the Iowan drift area were studied, and the constitution, physical features, and degree of modification of the till by weathering were noted. The recent improvement of wagon roads, construction of interurban electric railway lines and the regrading of the Chicago, Milwaukee and St. Paul railway have afforded many new exposures. The majority of the cuts in this area are less than fifteen feet deep, and few are so much as twenty feet. On account of the small amount of dissection of the Iowan area, there are localities where road cuts or excavations of any kind are few. In such areas a two-inch auger eight feet in length was used for making test borings.

The following is a generalized section of the deposits shown by these exposures:

GENERALIZED SECTION.

		Feet
4.	Soil, black to dirty brown, usually pebblelesss or pebbles rare; where thicker than two feet the lower part is yellow and looks like loess, thickness........	1 to 2½
3.	Pebble-line (in some cuts)	
2.	Leached till, light brownish yellow to buff, clayey matrix; pebbles of granite, greenstone, and chert—and some of felsite, basalt, dolerite, volcanic porphyry, quartzite, and vitreous quartz; some of the granite sound, some disintegrated; greenstone mostly fresh; absence of limestone pebbles and noncalcareous constituents conspicuous; thickness	3 to 5
	Grades rather abruptly into:	
1.	Calcareous till, limestone pebbles present together with the other varieties found in the leached zone, color changes by gradation downward from buff to gray or slate-color eight to ten feet from top of till-body.	

The Lithology of the Iowan Drift and Its Comparison With Other Drifts.

Rough determinations of lithologic composition were made by collecting and sorting pebbles from numerous exposures of each of the following drift sheets in Iowa, the Nebraskan, Kansan, Iowan, and Wisconsin drifts. The results of these, together with numerous similar estimates made by R. T. Chamberlin in 1907, are presented in tables in Appendix A for ready comparison. From Table 2 it will be seen that the pebbles of the unleached Iowan drift comprise mainly granites, greenstones, limestones, schists, quartzites, quartz, cherts and sandstone. It will be noted that the percentage of each constituent varies considerably from place to place, and that the general composition of this drift is not distinctive. This being the case, unless the two drifts are exposed in the same section with a weathered zone or interglacial deposits clearly marked between, one cannot always be sure that any particular section is in Iowan till and not Kansan. The only lithologic distinction which the Iowan drift sheet possesses seems to be the greater abundance of large granite bowlders in the eastern and central parts of the area. These bowlders are considered in Chapter V.

In general, however, it may be stated that the limestone content of the Wisconsin drift is higher than that of any other (See Table I); that the formation of ironstone concretions in the altered zone and the concentration of calcium carbonate in the unleached zone of the Iowan drift are less notable than is the case with the Kansan drift.[5] The latter point suggests that the Kansan drift has undergone more prolonged weathering than the Iowan.

THE OXIDATION OF THE TILL.

In most places oxidation to a buff or bright yellow tint has extended to depths below the reach of the eight-foot auger. Yet in many places bluish gray unoxidized till was reached in boring. As seen in cuts, oxidation was found, in most places, to have changed the original bluish gray or drab-gray color of the till to light buff to depths somewhat greater than the leaching had extended, that is, usually to depths of seven to ten feet. Below these depths the color gradually changes. The color in the oxidized part of the till generally ranges from light buff at the bottom to brown at the top. In many places, as in Bremer county, the upper part below the soil is a bright ocher-yellow, but rarely is it orange and seldom is there a distinct reddish tint as in the Kansan ferretto. In some places the bluish gray

[5]It should be noted that the true percentages of clay ironstones and calcareous concretions are not generally shown in the tables of estimates since in collecting pebbles, the writers aimed to avoid these secondary constituents.

till is considerably more dense and hard than the oxidized and leached till and grades below into dense, hard, dark, slate-colored till. In these instances the unoxidized till, at least, is probably Kansan.

If the interglacial deposits or the red ferretto characteristic of the top of the Kansan have been removed by erosion and a deposit of Iowan till left instead a given cut may show buff Iowan till over buff Kansan till with no apparent break between. This is one of the factors that makes the determination of the exact limits of the Iowan drift well-nigh impossible. It certainly is not safe to regard all the buff or yellow till as Iowan and only the blue-gray or blue-black unoxidized part as Kansan, as seems to have been done in some cases.

Fortunately, however, as described on page 92 there are a number of places where the weathered zone and interglacial soil at the top of what is regarded as Kansan drift are well preserved with an overlying deposit of till, presumably Iowan.

THE EFFECTS OF LEACHING.

Examination was made of sixty-five exposures which showed the change from calcareous to leached till. The clayey matrix was tested with cold dilute hydrochloric acid. The limestone pebbles were present in the former but mostly absent from the latter. As shown in Table 3, Appendix A, seven estimates where the pebbles were taken only from the leached upper part of the drift show an average of but three per cent of limestone and dolomite, while the percentages of the relatively insoluble constituents were correspondingly higher.

Besides examining the exposures, 250 auger borings were made, where cuts were not available, to ascertain the depth of the leached zone and character of the till. One hundred and sixty-five of these were in the interior of the area and eighty-five nearer the border.

Following is a tabulation of the results obtained by examining the exposures and making auger borings:

Depth of Leaching From Top of Till	Number of Cuts	Number of Borings	Percentage of Cuts	Percentage of Borings
0-1	1	1	2	1
1-1½	3	12	5	7
2-2½	7	25	12	15
3-3½	24	55	42	33
4-4½	12	37	21	23
5-5½	9	18	15	11
6-6½	2	13	2	8
7-8	1	4	1	2
Total	59	165	100	100

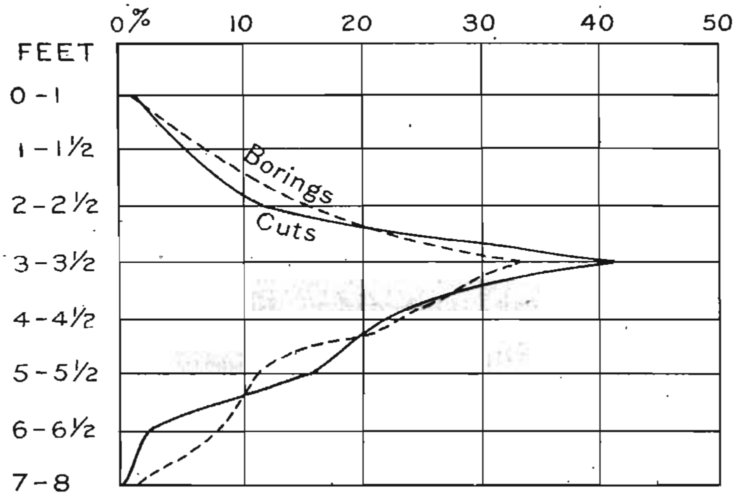


Fig. 2.—Diagram of percentages of cuts and borings showing different depths of leaching of the uppermost till at various places in the area of the Iowan drift.

The curve in figure 2 represents graphically the foregoing results.

This compilation shows that the larger number of cuts and borings give a depth of leaching of three to three and one-half feet; that seventy-eight per cent of the cuts and sixty-seven per cent of the borings indicate a range of depth from three to five and one-half feet; and that only one per cent of the cuts and two per cent of the borings showed as much as eight feet of leaching.

In the border belt the depth of leaching is less uniform and averages somewhat more. Fifty-four per cent of the borings showed the depth of leaching as four to six and one-half feet, thirty-two per cent less than four feet, and fourteen per cent as much as seven and one-half feet.

The overlying loesslike clay.—Generally soil and loesslike clay one to two and one-half feet thick overlie the till of the Iowan area. This deposit is not included in the measurements of leached till. It appears to be a thin mantle of loess which has largely lost some of its typical character as the result of leaching, freezing and thawing, burrowing of animals, the influence of vegetation and mixing with humus in the upper foot or so. Where the deposit is more than two and one-half feet thick, its lower part is identical in character with loess. As seen in cuts it is generally separated from the till by a distinct line of pebbles, which are probably the residue from wash and wind-erosion of the upper part of the till.

If this thin coating of loess was deposited as calcareous material immediately after the deposition of the till, its thickness should be included in the depth of leaching which has taken place since the till was deposited. If it was added later as non-calcareous material derived from the weathered surface of the till, then its effect on the leaching of the underlying till has been slight. A part of it may have had the former history, a part of it the latter.

COMPARISON WITH THE KANSAN TILL.

The oxidation of the Kansan drift.—The uppermost till of the unquestioned Kansan area was studied in railroad sections and road cuts to the south and east of the Iowan drift area. Its oxidation, decomposition, and leaching were carefully noted. The change in the Kansan drift as the result of oxidation differs from that of the uppermost drift of the Iowan area in two particulars,—in degree and in depth. In most of the places seen the Kansan drift is overlain by loess. The prevalence of a reddish brown or dark brown ferretto zone at the top of the till and beneath the loess is a conspicuous phenomenon. This ferretto, which averages one to one and one-half feet thick, consists of a dense, sticky clay containing many decomposed granites, greenstones, and other igneous rocks, together with quartzites, quartz, cherts, and clay ironstones. It grades downward into brownish and yellowish leached till. The material has the appearance of being the relatively insoluble residuum of prolonged leaching, oxidation, decomposition, and dehydration of a somewhat greater thickness of the upper part of the till. Its advanced state of decay matches its setting in the much eroded Kansan area. In many exposures the ferretto is cut off well up in the eroded slope as though it had been formed before the present stage of dissection was reached.

The ferretto band is fairly persistent in the crests of the ridges throughout those dissected parts of the Kansan drift area which were visited by the writers, and it is strongly in contrast with the brownish yellow color of the upper part of the drift in the Iowan area. The ferretto was seen within the boundaries of the Iowan area, in three or four places only. At one or two of these there was evidence of mechanical mixing with fresher till, as if the ferretto had been disturbed by an overriding ice-sheet. The other cases were in isolated localities of sharp, mature erosion, where the topography lacks the mantled aspect.

Not only is there a significant difference between the degree of oxidation of the uppermost till in the Iowan area and that of adjacent parts of the Kansan areas, but also in the depth of oxidation. The Kansan drift is oxidized to depths of fifteen to twenty-five feet below the base of the loess, as compared with eight to ten feet for the Iowan drift.

While the writers regard this sort of evidence as entirely legitimate, they do not think these measurements, those given above, or those following, can be applied indiscriminately in other areas. The similarity in climate at present between northeastern Iowa and adjacent parts of southern Iowa and Illinois seems to warrant direct comparisons of the amount of modification by weathering of the several drift sheets. Going to another region, however, as, for example, to the drier climates farther northwest, the same differences may not be found. If contrasts in degree and in depth of oxidation of deposits in two areas, lying side by side, are to be regarded as at all indicative of difference in age, the data cited are certainly significant. The strong oxidation is found where there is the deeply dissected topography of the Kansan, the moderate oxidation is associated with the mantled and little eroded topography of the Iowan area. This evidence seems to support the conclusion of difference in age reached from the study of the topography.

The leaching of the Kansan drift.—If mature erosion, the presence of a ferretto, and greater depth of oxidation distinguish the drift of the Kansan area from that of the Iowan area and indicate a greater age for the former, the leaching of the Kansan till should at least be consistent with this view.

In critically examining data bearing on the leaching of the Kansan till, attention to the topographic position of the exposure is important. In a sharply dissected topography, the leaching of the till on the lower slopes must date from the time that the drift in that topographic position was brought within the zone of leaching by the removal of the overlying material, i. e., from a time when most of the erosion had been accomplished. The diagram (figure 3) of a specific case illustrates

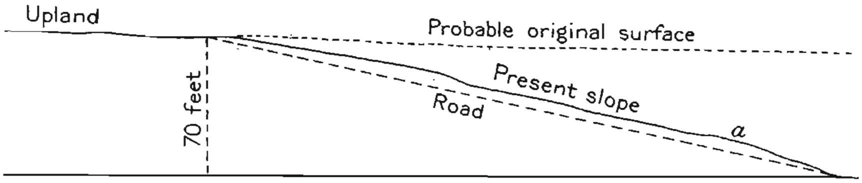


Fig. 3.—Diagram of valley slope in Kansan drift area four miles northeast of Victor (Iowa County, Hartford township; Township 80 North, Range 12 west, east line southeast quarter section 3. *a*. Position of road cut showing till leached to depth of five feet.

a prevalent condition. A road cut at *a* shows a leached zone of five feet. Obviously, this thickness may have been added to by deposition or subtracted from by slope-wash. But if we assume that the thickness is a true record of the depth of leaching in place, it still can not be taken as indicative of the full age of the drift but rather as a measure of the time since that particular portion of the drift was subjected to leaching.

One must discriminate also in interpreting the data collected from railroad cuts, similarly located. To illustrate again, reference may be made to a Chicago, Milwaukee and St. Paul railway cut in a locality of sharp dissection in Tama county, west of Vining, Otter Creek township, southwest quarter of section 13. The cut is 150 yards long, has a maximum depth of 25 feet, and transects the lower parts of two long spurs. In vertical section the relations are as follows (figure 4).

At *a* a ferretto and a leached zone of till four or five feet thick lies beneath calcareous loess. At *b* and *b*[1] these are absent and

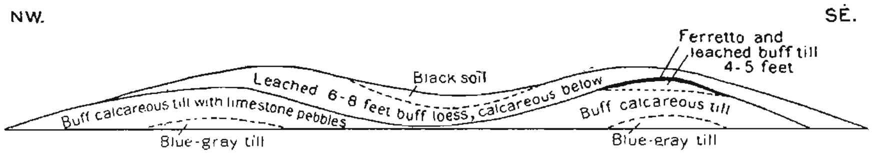


Fig. 4.—Diagram of drift exposed in Chicago, Milwaukee & St. Paul Railway cut three miles west of Vining, Tama County, Iowa, showing relation of loess to weathered and unweathered Kansan drift. Length 450 feet. Height 25 feet.

the calcareous loess rests directly on calcareous till containing limestone pebbles. The relations at *a* record an interval of leaching and oxidation between the development of the surface of the till at this horizon and the deposition of the overlying loess. This record, however, covers only a fraction of the interval between the deposition of the till and the deposition of the loess. It lacks at least the time consumed in the erosion of the original drift plain down to this horizon. Furthermore, the difference in relations at *a* and *b* are suggestive of the unreliable character of the data even for the interval between the slope development and the deposition of the loess. If the relations at b^1 only were known, there would be absolutely no record of the interval of leaching. Obviously, erosion, or slope-wash, at *b* and b^1 overtook and surpassed the rate of leaching so that the weathered zone was removed before the loess was deposited.

It is evident from such conditions that the depths of leaching ascertained from exposures on slopes may be much less than the actual total amount of leaching of the Kansan till. Better places for such measurements would probably be in cuts through the upland divides, but such are few.

A cut forty-five feet deep, about three-fourths mile east of Vining, situated almost half way up the slope of a spur, shows as much as seven feet of leaching at the top of the till below calcareous loess, which in turn is overlain by leached loess. But even here the top of the till is considerably below the general upland level and its surface is rounded.

West of Melbourne, Marshall county, there are three cuts within four miles, similarly situated topographically, which show a like depth of leaching, and four others higher up on the slopes of spurs, which show leaching to depths of twelve, thirteen, twelve and eleven feet, respectively. In all of these cuts the leaching took place before the loess was deposited.

Two and one-half miles west of Rhodes, Marshall county, at the edge of the Wisconsin drift sheet, in a cut seventy feet deep, ten feet of noncalcareous gumbo and ten feet of leached Kansan till overlie calcareous Kansan till and underlie loess and Wisconsin drift. If the gumbo is the product of weathering of the Kansan till, as is believed by some recent workers, the leached zone in this case would be at least twenty feet.

If the gumbo is really the concentration of the least readily soluble constituents of the upper part of the till, i. e., the residuum of long leaching, each foot of its thickness represents more than one foot of the original till before the soluble parts were removed. Whether or not the gumbo is such, it seems clear that the ferretto zone is the result of such concentration, together with oxidation, and represents a somewhat greater thickness of unleached till.

It appears that some appreciable part of the till is composed of the soluble part of the limestone pebbles, since these comprise nearly fifty per cent of all the pebbles in the drift and with these goes the calcareous rock flour in the matrix of the till. If accurate determinations were being made of the total depths of leaching, some small amount should be added to the present thicknesses of the leached zone. In the rough determinations made in this investigation, however, this factor may be omitted.

Comparing then the leached zone of the Kansan drift near the original upland in adjacent areas with the leached zone in the Iowan drift area, depths of eleven to thirteen feet in the former as compared with three to five and one-half feet in the latter emphasize the greater age of the Kansan drift over that of the Iowan.

But yet the whole difference has not been pointed out. The rate of leaching undoubtedly decreases with depth, due to (1) the less amount of percolating water on account of capillary action bringing a part back to the surface; (2) the slower movement of the ground water with increased compactness, and (3) the decreased solvent action of the water as the result of the dissolving of some materials during descent. Hence, the relative length of time is probably something more than the ratio of the foregoing figures.

Another point of importance remains to be noted. The leached zone of the Kansan drift lies beneath calcareous loess, which in turn is overlain by leached loess five to ten feet thick. This stratigraphic relation shows that the period of leaching of the Kansan drift is separated from the present by an interval of loess deposition and of subsequent leaching of the loess to depths varying from five to ten feet. In most of the Iowan drift area, the leaching of the drift has continued to the present without much interruption. Therefore, in order to make proper comparisons, the equivalent of the leaching of the loess should be added to the leached zone of the Kansan.

The phenomena of weathering, therefore, seem to indicate that there is in northeastern Iowa a drift sheet which is young as compared with the Kansan drift.

COMPARISON WITH THE WISCONSIN TILL.

The Wisconsin till was examined for purposes of comparison at several points from Cerro Gordo county south to Jasper county and along the Chicago, Milwaukee and St. Paul railway across the southern part of the Wisconsin drift plain.

In practically all places the oxidation of the Wisconsin till is to a light buff tint, and the leached zone is in general two to three feet deep. In many places limestone pebbles are present at or near the surface. Locally there are occurrences of loess on the Wisconsin drift but the amount is generally negligible. The topography of the Wisconsin is typically glacial and the amount of erosion is slight except near major streams. There seems to be little ground for doubt that the Iowan drift is distinctly older than the Wisconsin.

CHAPTER III

THE SUPER-KANSAN "GUMBO," ITS CHARACTER, RELATIONS, AND SIGNIFICANCE.

In the Kansan Drift Area

An overlying later till may not be distinctly separable in many places from an underlying earlier till, especially if no interglacial deposits or weathered zone have survived the abrasion of the later ice sheet. Nevertheless, it would be strange, if, in an area as large as 9,000 square miles, and with the Iowan drift as thin as has been described there should not be found unmistakable evidence of separation from the Kansan till.

A number of exposures have been found in northeastern Iowa showing what appear to be remnants of the super-Kansan "gumbo" with, in some places, a black carbonaceous layer representing an old soil at the top and above this a later till of moderate thickness. In these places the supposed Iowan till is clearly separated from the older drift. The character, distribution, and mode of origin of the super-Kansan "gumbo" of southern Iowa are to be discussed by Doctor Kay in a forthcoming paper. A preliminary paper has been published already by him.[6] So important are the occurrences of "gumbo" of this age to the question of the differentiation of a post-Kansan drift in northeastern Iowa that a brief description of "gumbo" exposures observed by the writers is presented here.

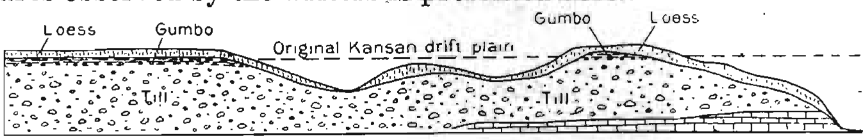


Fig. 5.—Diagram showing relations of super-Kansan "gumbo" and of loess to remnants of the original Kansan drift plain.

Overlying the Kansan till on the uplands, that is, on remnants of the original Kansan plain (figure 5) throughout much of southern Iowa is a deposit of clay which, for want of a better name, may be called "gumbo."[7] This clay is dense, sticky, and

[6]Kay, Geo. F., Some Features of the Kansan Drift in southern Iowa: Bull. Geol. Soc. America, Vol. 27, pp. 115-117.

[7]Professor Kay has recently proposed the name "gumbotil" for this and similar deposits. See Kay, Geo. F., Gumbotil, a new term in Pleistocene geology: Science, N. S., Vol. XLIV, pp. 637-638, 1916.

very slippery when wet. It is generally noncalcareous and dull gray in color. Sometimes the color is gray mottled with brown and the upper part is oxidized to a reddish or brownish tint. It has not the loose porous texture of loess and the sun-dried face of the exposure generally differs from that of loess in being checked by sun cracks. A fresh-fractured surface of a lump of "gumbo" often shows minute pellets, a millimeter or so in diameter, of clay, or sometimes of oxide of iron or manganese dioxide, such as characterize the so-called "buckshot" clays. Removal of the pellets leaves the surface pitted with little concave depressions.

There are places where the "gumbo" is rather sandy, though even here a sticky clay matrix makes the grains adhesive rather than loose; so also the clay may contain, in patches, small angular bits of feldspar, quartz, and other minerals such as might result from the disintegration of included granite pebbles or bowlders. Some instances are reported by Doctor Kay of granite bowlders being included and still retaining their form though so much disintegrated as to be easily cut through by a pick or spade. The "gumbo" is nowhere very stony but it generally contains scattered small pebbles, mostly less than one inch in diameter. These are predominantly of chert and quartz but with these are occasional crystallines and quartzites. An estimate of pebbles collected from a road cut in the "gumbo" one-half mile south of Russell, Lucas county, showed the following:

	Per cent
Quartz	38.3
Chert	38.
Quartzite	8.3
Granite	8.3
Basalt	8.3
Fine-grained granite	1.6
	100.0

Careful examination of numerous exposures shows no lamination of the clay such as usually characterizes waterlaid silts and shows no definite line of demarcation separating this clay from the Kansan till below. The change from the stony till to the less stony "gumbo" above takes place in a narrow zone but it seems clearly to be one of gradation. The till may be leached of its calcareous material for a few feet below the base of the "gumbo" or it may be highly calcareous nearly or quite to the narrow zone of transition. The limestone and dolomite pebbles and most of the crystallines become smaller and smaller from the base of the transition zone up into the "gumbo," where they disappear; and the few crystalline pebbles which remain are usually badly decomposed and are smaller and still fewer toward the top of the "gumbo." This condition gives rise to the suggestion that the "gumbo" is not a distinct and later deposit but that it is the residuum of thorough weathering and long leaching of the upper part of the Kansan till.

The "gumbo" where seen by the writers ranges in thickness from a few feet to eighteen feet. If it really is the residuum of the upper part of the Kansan till after the more readily soluble constituents have been removed by leaching, it evidently represents a very long time of exposure since the disappearance of the Kansan ice sheet.

The upper part of the "gumbo" is generally colored reddish or brownish as the result of oxidation and hydration and where the gray clay has been burned for brick or railroad ballast, it changes to a red color. The part of the till immediately beneath the "gumbo" is also generally oxidized orange, brownish, or buff, and the latter tint may continue downward fifteen or twenty feet before grading into the original blue-gray or blue-black color of the unoxidized till.

With some exceptions, which may be the result of redeposition, the "gumbo" lies on the upland remnants of the Kansan drift plain. It does not extend down the slopes but is cut off by erosion. From this it is inferred that the "gumbo" was developed (possibly when the plain was low-lying) before any considerable amount of dissection of the Kansan plain had been accomplished. If all these suggestions are really true, it is apparent that the interval between the Kansan and Illinoian stages of glaciation, the Yarmouth interval, was of very long duration, for studies in southeastern Iowa and western Illinois (see page 199) show that the super-Kansan "gumbo" there underlies the Illinoian drift.

In the Kansan area, this "gumbo" lies on top of the Kansan drift, and near the Iowan-Kansan border it underlies loess. Wherever the loess is more than six or eight feet thick, its base is calcareous, whereas the "gumbo" is leached and the upper one foot or so is oxidized to a brownish gray with reddish specks scattered promiscuously. There is no doubt that the "gumbo" is much older than the loess.

These various questions will be considered by Doctor Kay in his forthcoming paper. Whatever may be the final conclusion in regard to them, one thing seems to be clear, the "gumbo" has so wide a development on the remnants of the Kansan plain that whatever its origin it seems to mark fairly definitely the stratigraphic horizon of the original top of the Kansan drift, even in the Iowan drift area.[8] The only qualification of this statement as far as the relations of the Iowan drift are concerned arises from the fact, (discussed in another connection) that a similar bed of "gumbo" occurs in places at the top of the Nebraskan drift. The finding of somewhat similar deposits at the top of the Illinoian drift while affecting the interpretation as to relative age of the Iowan and Illinoian drifts does not directly affect the question of the Iowan drift being a distinct post-Kansan drift sheet.

In the Iowan Drift Area

In the Iowan drift area a number of exposures of "gumbo," probably the super-Kansan "gumbo," have been observed, and overlying this is a deposit of glacial till. If this "gumbo" is really super-Kansan the drift over it is clearly the product of a distinct ice invasion of post-Kansan age. This upper till the writers believe to be the Iowan till. This "gumbo" is identical in character with that found on the Kansan of southern Iowa. It has, in places, a black carbonaceous layer, an old soil, at the top. So far as observed it is noncalcareous while the overlying till is in some places seen to be highly calcareous. At other exposures the drift is so thin that it has been leached of its calcareous constituents. The observed exposures of the "gumbo" are mostly in the higher parts of the Iowan drift area, in those places where it would be expected that remnants of the original Kansan plain might be preserved. These exposures are mostly in recently-made cuts for electric, steam, and wagon roads, so that but few

[8]For purpose of record and to make the data readily accessible for study, there are inserted in Appendix B notes on exposures of the super-Kansan "gumbo" in the area seen by the writers immediately south and east of the Iowan drift area.

of them seem to have been observed during the earlier studies of the area and such as were seen were not recognized as having the significance now attached to them. Besides being observed in exposures, the "gumbo" was encountered in some of the borings made by the writers. These new items of evidence are important as lending definite support to the theory of post-Kansan glaciation in northeastern Iowa. Considering the fact that only a very small part of the roads of the Iowan area were actually traversed during these two field seasons, the study being in the nature of a review rather than a detailed survey, it is not remarkable that so small a number of exposures of the gumbo were found. Further examination throughout the area along the roads not already traversed may yield additional data. So important is the evidence in hand that detailed descriptions of the occurrences noted are given herewith. They may thus be compared with the descriptions of occurrences of "gumbo" in the Kansan area and in the Illinoian drift area. (See Appendix B.)

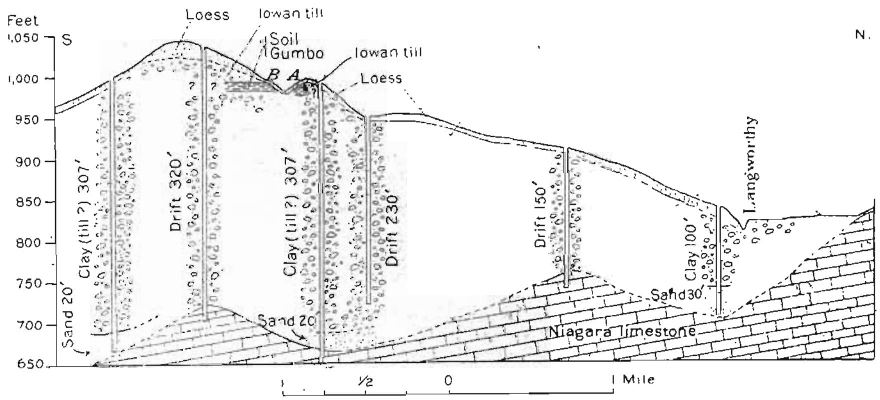


Fig. 6.—Diagrammatic section across ridge south of Langworthy, Iowa, showing relations of loess: (1) Iowan till; (2) Yarmouth soil and super-Kansan "gumbo"; (3) Kansan drift; (4) earlier deposits.

JONES COUNTY.

One of the most significant exposures is in Jones county on the top of the ridge between Monticello and Anamosa. The relations are shown in figure 6. The general relation of this ridge are shown on a smaller scale in figure 1.

The exposure is south of Langworthy and about five miles northeast of Anamosa in the south slope of a lobe of the ridge, in

Jones county, Wayne township, (Township 85 North, Range 3 West, section 30 near the middle of the north line). The beds exposed in the road cut and penetrated by boring with an auger are as follows (see A, figure 6):

DRIFT SOUTH OF LANGWORTHY, IOWA.

		Feet.
5.	Loess, leached	3
4.	Till (Iowan) brown, rather sandy, leached	3
3.	Soil band, black to brown, with carbonaceous matter	few inches
2.	"Gumbo" (super-Kansan), noncalcareous, gray, dense clay, very sticky when wet	8-10
1.	Till (Kansan) is slightly exposed at foot of the slope.	

Across the sag to the south (B, figure 6) similar relations are shown at the same level. The cut and boring here showed:

DRIFT SOUTH OF LANGWORTHY, IOWA.

		Feet.
5.	Loess	5
4.	Till, (Iowan), brown, leached	5¼
3.	Soil band, black	few inches
2.	"Gumbo" (super-Kansan), gray, noncalcareous clay	4
1.	Till (Kansan), rusty, brown, leached	4
1.	Till (Kansan) calcareous.	

The "gumbo" is like that overlying the Kansan drift in southern Iowa and is believed to mark the same horizon.

Neighboring wells show this ridge to be wholly of drift and to overlie an old valley cut in the rock. Numerous wells have penetrated 200 to 400 feet or more of drift and underlying sand and gravel. It is quite possible that this includes both Kansan and pre-Kansan, besides Iowan, deposits. Farther southeast the ridge is much dissected and numerous cuts show the highly oxidized upper part of the Kansan till but with no overlying later till. The loess-mantled ridge is cut by sharp ravines where crossed by the Anamosa-Monticello road, on which are the exposures described above, but farther northwest the surface becomes smoother and less dissected. These relations indicate that the ridge of Kansan drift was overridden by the Iowan ice as far southeast as this road but not much if any farther. The buried soil and "gumbo" thus mark the horizon of the original Kansan plain which is here nearly 1,000 feet above sea level.

DELAWARE COUNTY.

In the southwestern part of Delaware county where the mantled topography is very well developed there is a belt of thick drift and here the super-Kansan "gumbo" and soil are found beneath the Iowan till. The "gumbo" was found by Mr. Leighton, exposed about five miles northeast of Ryan (Milo township, Township 88 North, Range 5 West, section 34, west line of southwest quarter) in a road cut in a small hill on top of the ridge at 1060 ± feet above sea level. The cut, together with a boring, showed the following:

DRIFT NORTHEAST OF RYAN, IOWA.

		Feet.
5.	Soil, pebbly	1
4.	Till (Iowan), bright yellow, calcareous nearly to top	3
3.	Silt, gray to drab, slightly calcareous	3
2.	"Gumbo" (super-Kansan), drab to ashen-gray silt, contains considerable grit and some pebbles, noncalcareous	4
1.	Till (Kansan), reddish brown at top with clay ironstones and ferruginous streaks, leached five feet, calcareous below	5+

This hillock is one of a group having somewhat the appearance of a moraine.

In a boring on the ridge crest on the opposite side of Lime creek valley at a point about two miles southeast of Ryan (Hazel Green township, Township 87 North, Range 5 West, section 29, north line of northwest quarter) the following similar series of beds were penetrated:

DRIFT SOUTHEAST OF RYAN, IOWA.

		Feet.
5.	Sand	4½
4.	Loess, yellow, leached	½
3.	Till (Iowan), yellow, leached	1
2.	Silt, very dark gray, loesslike in texture, noncalcareous	1½
1.	"Gumbo"-like clay (super-Kansan), gray, mottled brownish, containing quartz pebbles and some decomposed greenstones and granite pebbles, penetrated	½

This is on the highest part of the broad ridge at 1080± feet above sea level, in a district where wells show 160 feet of drift.

Later, in company with R. D. Salisbury, Frank Leverett, and G. F. Kay Mr. Alden observed several exposures (at 1040± feet above sea level) in cuts on the north-south road between sections 28 and 29, 32 and 33, showing:

DRIFT SOUTHEAST OF RYAN, IOWA.

3. Till (Iowan), leached, a few feet.
2. Soil, black, carbonaceous, a few inches.
1. "Gumbo" (super-Kansan?), dense, gray, noncalcareous clay containing small pebbles; exposed for a few feet.

BUCHANAN COUNTY.

On going northwest along the same belt of relatively high country and thick drift some exposures were found in eastern Buchanan county.

About four miles southwest of Masonville (Middlefield township, Township 88 North, Range 7 West, section 3, west line) the north-south road crosses the crest of a high ridge, the continuation of the belt of thick drift seen farther southeast. The crest stands 1,100 feet above sea level. Wells on this ridge are said to penetrate 200 to 265 feet of drift so that it appears that a valley cut in the rock underlies the ridge. A cut and boring on the crest of the ridge showed:

DRIFT SOUTHWEST OF MASONVILLE, IOWA.

	Feet.
Soil, black, sandy, pebbly loam	1
Till (Iowan), brownish yellow, leached four feet and calcareous below	6+

At a point fifty to sixty feet below the top of the south slope a bed of "gumbo" was slightly exposed in the ditch (at 1050± feet above sea level) beneath a thin covering of till. The ditch and boring showed:

DRIFT SOUTHWEST OF MASONVILLE, IOWA.

	Feet.
Loam, black, pebbly	1½
Till (Iowan), brown, leached	2
"Gumbo" (super-Kansan) dense, sticky, gray, noncalcareous	3+

If one may judge from the relations noted elsewhere the "gumbo" probably extends back horizontally into the ridge so that there may be fifty feet of Iowan till above it. The underlying till is not exposed but the wells of the region indicate that there is probably a considerable thickness below the horizon of the "gumbo."

About six miles north of this place (Fremont township, Township 89 North, Range 7 West, section 11, west line of northwest quarter) in the same high belt of thick drift, a boring on the slope of the ridge about fifty feet below the top (at 1,090-1,100 feet above tide) showed:

DRIFT NORTHWEST OF MASONVILLE, IOWA.

	Feet.
Till (Iowan), brown, leached and very stony	1½
"Gumbo" (super-Kansan), dense, gray, noncalcareous clay	4
Clay, sandy, gray	2+

A boring on the crest of the ridge a mile farther north at 1,140 feet above sea level showed:

DRIFT NORTHWEST OF MASONVILLE, IOWA.

	Feet.
Soil, black	1
Till (Iowan), yellow, leached	5
Till, calcareous below	5½+

Here again it appears there may be a considerable thickness of Iowan drift above the horizon of the "gumbo" in the body of the ridge though it is very thin at the point of outcrop in the slope.

A cut on the Chicago, Anamosa and Northern railway one mile east of Kiene in Middlefield township, Township 88 North, Range 7 West, section 34, southwest quarter, exposed the following:

DRIFT ON CHICAGO, ANAMOSA & NORTHERN RAILWAY EAST OF KIENE, IOWA.

		Feet.
6.	Humus, dark, and brown pebbleless clay	1-1½
5.	Line of pebbles.	
4.	Till, buff to brown, leached, clayey	4-6
3.	Till, similar to above, but calcareous, with abundant limestone pebbles	2
—	Distinct line of division, not a gradation zone.	
2.	Clay, dense, dark slate colored, ashen gray in places and oxidized brown along joints and bedding or cleavage planes. Suggests the super-Kansan "gumbo"	5
1.	This grades down into dark, slate-colored, pebbly clay till, brown in places, noncalcareous.	

The lower till No. 1, resembles the unoxidized Kansan except in being noncalcareous where tested. The upper till, Nos. 3 and 4, above the distinct division line, is like that generally present at the surface in the Iowan area.

LINN COUNTY.

In Linn county about four miles northeast of Center Point (Otter Creek township, Township 85 North, Range 7 West, section 4, south line) a boring made in a shallow road cut on the gently undulating plain showed the following:

DRIFT NORTHEAST OF CENTER POINT, IOWA.

	Feet.
Till (Iowan), leached	3-4
Clay, yellowish gray, gritty and noncalcareous and of texture suggesting super-Kansan "gumbo"	3

Three miles northwest of Central City (Jackson township, Township 86 North, Range 6 West, section 21, north of center) "gumbo" is exposed beneath till in a road cut near the top of the east slope of the hill. The road cut and test bores made in the bottom of the cut show the following beds:

DRIFT NORTHWEST OF CENTRAL CITY, IOWA.

		Feet.
4.	Soil, loamy, pebbly	1½
3.	Till (Iowan), brownish yellow, leached	2½
3.	Till (Iowan), calcareous, yellow, grading downward into gray	6
2.	"Gumbo" (super-Kansan), noncalcareous, black soil with wood at top, dark gray below, with "buckshot" texture and rare small pebbles of chert and quartz (one dolerite found)	3
1.	Sand and gravel.	

This exposure is about twenty-five feet below the top of the ridge and about 120 feet above Wapsipinicon river, one mile distant. The relations here and at the following exposures suggest that a thin bed of Kansan till underlain by sand or sand and gravel has been wholly changed to "gumbo."

In the southwestern part of the county four miles east of Atkins (Linn county, Clinton township, Township 83 North, Range 8 West, section 16, southwest quarter) a cut on the Chicago, Milwaukee & St. Paul railway through the southeast end of a paha shows the following:

DRIFT EAST OF ATKINS, IOWA.

		Feet.
5.	Loess, buff, calcareous in lower part	15
4.	Till (?) (Iowan?), reddish to yellow leached pebbly clay	0-1
3.	"Gumbo" (?), soft, dull brownish to reddish gray clay, noncalcareous and with some small pebbles and sand grains	2½-3
2.	Sand and gravel, buff	3
1.	Till (Kansan?), leached, with rotten pebbles and bowlders	1
1.	Till (Kansan?), gray, calcareous	1-2

BENTON COUNTY.

Three or four miles southeast of Brandon (Harrison township, Township 86 North, Range 10 West, section 12, northwest quarter) the deeper part of a cut on the electric railroad, on top of the ridge (at 900± feet above sea level) showed the following:

DRIFT SOUTHEAST OF BRANDON, IOWA.

		Feet.
5.	Soil, dark, pebbly loam	½-1
4.	Gravel, stratified, rusty reddish brown, pebbles somewhat decayed, clay ironstone present, noncalcareous	0-4
3.	Sand and gravel, brown, cross-bedded, noncalcareous	3-4
2.	"Gumbo", dense, sticky, gray, noncalcareous, pebbleless clay	3
1.	Grading down, in one part, into gray clayey sand to loose sand. In the lower part a bright yellow streak and below this the nearly white sand, total exposed	6

The "gumbo" (No. 2) resembles the super-Kansan "gumbo" of southern Iowa, but it is overlain by sand and gravel and grades down into loose sand.

Two miles north of Newhall (Eldorado township, Township 83 North, Range 10 West) (at 940± feet above tide) "gumbo" was observed in cuts on the road north and west of the southeast corner of section 1 about ten feet below the top of the slopes. Cuts and borings gave the following section:

DRIFT NORTH OF NEWHALL, IOWA.

		Feet.
3.	Till (Iowan), yellow, leached	4
2.	Silt, light gray, noncalcareous	½
1.	"Gumbo" (super-Kansan?), black with carbonaceous matter at top, dark gray below, dense rubber-like clay, noncalcareous, exposed	A few feet

This is on one of the highest tracts in this part of the country. The "gumbo" is cut off by the slope, apparently having been eroded prior to the deposition of the upper till which now mantles the slope and covers the "gumbo."

Three miles south of Vinton (Eden township, Township 84 North, Range 10 West, section 3) a boring on the ridge just south of the northwest corner penetrated the following:

DRIFT SOUTH OF VINTON, IOWA.

		Feet.
4.	Loess, brownish yellow, leached	2
3.	Till (Iowan), brownish yellow, leached	3
2.	"Gumbo"-like clay (super-Kanson), dark gray, leached	1
1.	Till (Kansan), brownish yellow, leached; penetrated	2

BLACK HAWK COUNTY.

In the southwestern part of Black Hawk county the following was found in the Chicago & North Western railway cut one-half mile northwest of Voorhies. Part of the section was determined by boring at two different levels, the lower hole reaching a depth of five and one-half feet below the track.

DRIFT NORTHWEST OF VOORHIES, IOWA.

		Feet.
7.	Clay, loesslike	3½
6.	Till (Iowan), buff, leached, clayey	3-3½
5.	Till (Iowan), buff, calcareous	1½
4.	Clay, dense bluish gray, noncalcareous, containing small quartz pebbles; "gumbo" (?)	3-3½
3.	Clay (Kansan till), brown to gray, leached, pebbly	½
2.	Clay, brownish gray, mostly leached but calcareous in spots or with small limestone pebbles, crystalline pebbles rotten (Kansan till)	7
1.	Till (Kansan), dense, buff, calcareous	5½

While the part of this section determined by the two borings may not be exactly continuous, it seems probable that Nos. 5 and 6 comprise the Iowan till. Number 4 is like the super-Kansan "gumbo," and Nos. 1, 2, and 3 are probably Kansan till, including the gradation zone.

This cut was examined by Prof. M. F. Arey and described somewhat differently in his report[9]. At the time of the writers' visit in 1914 the section was obscured by vegetation.

FAYETTE COUNTY.

To the northwest, in Fayette county, one of the best exposures was found five miles west of West Union (Windsor township, Township 94 North, Range 9 West, section 16, north line of the northeast quarter), in a road cut through a small ridge or lobe of the slope at 1200± feet above sea level. The cut and boring showed the following:

DRIFT WEST OF WEST UNION, IOWA.

		Feet.	Inches.
5.	Till (Iowan), yellow, calcareous in lower part	10	
4.	Clay, loesslike, gray above, rusty brown in lower part	1½	
3.	Soil, black carbonaceous layer		1-3
2.	"Gumbo" (super-Kansan) dense, gray clay, noncalcareous	5±	
1.	Till (Kansan), rusty brown, leached	3½	
1.	Till (Kansan), calcareous.		

The soil and "gumbo" were exposed at both ends of the cut, but were below the level of the road in the middle of the cut. A boring through No. 4 in the bottom of the middle of the cut showed that the soil (No. 3) and "gumbo" (No. 2) really extend

[9]Iowa Geological Survey, Vol. XVI, p. 443, 1905.

through the ridge. A boring in the bottom of the ten-foot cut on the east line of the northeast quarter of the same section showed the black soil No. 3 and "gumbo" No. 2 to be present there also.

Two miles south, on the west line of the northwest quarter of section 27 (at 1220 feet above sea level) a boring with the auger penetrated the following:

DRIFT EAST OF HAWKEYE, IOWA.

		Feet.
4.	Soil, dark, pebbly.	
3.	Till (Iowan), yellow, sandy, leached....................	3
2.	Soil, dark, carbonaceous band.	
1.	"Gumbo" (super-Kansan), dense, tough, rubber-like gray clay	3+

These occurrences of the buried soil and "gumbo" are in the higher parts of the gently undulating upland plain at 1140± feet above sea level.

HOWARD COUNTY.

Still farther north near the eastern border of the Iowan area in Howard county, an exposure in the new pit at the brick yard just north of the railroad, together with a boring made in the bottom, showed:

DRIFT AT CRESCO.

		Feet.
3.	Soil, pebbly	½-1
2.	Till (Iowan), brownish to yellow, sandy, leached, with crystalline pebbles and bowlders up to two feet in diameter	2-3
1.	Clay, "gumbo"-like, (super-Kansan), noncalcareous, "buckshot" texture in places, upper few inches to one foot light drab, darker drab two to four feet (as though colored by carbonaceous material), light greenish drab, then mottled brownish yellow to drab below...........	7+

In this connection the following description of exposures at Cresco from the notes of R. T. Chamberlin, made July 18, 1907, is of interest. This shows the presence of calcareous till (Kansan) below the gummy clay.

Cresco brick yard.—South pit, this is the deepest pit but is not used at present. At northwest end of this pit the bank shows three and one-half feet of yellow brown Iowan drift noncalcareous throughout. The upper portion merges into the surface dirt. I failed to find a single limestone pebble in it even after a careful search. There are frequent cherts and a good many quartzites and the tiny pebbles of gray or white granite and other light-colored igneous rocks which are so characteristic of the Iowan. Below the Iowan is a nondescript gummy clay mixed with some sandy layers which looks very much like interglacial material. The gummy clay contains many of the polished quartz pebbles and may have been washed in from a gummy portion of the older drifts during the Buchanan period. It is noncalcareous.

I looked over the bank of Iowan very carefully, noting carefully several hundred pebbles—in fact all that could be seen in some twenty feet of bank, collecting all the suspicious cherts that might possibly prove to be still calcareous but though I split open and tested with acid fifty or more of these (chiefly cherts for I could spot the igneous rocks readily) there was not a single pebble that effervesced to the slightest degree.

The bottom of the brickyard is strewn with numerous large bowlders of the Iowan type, doubtless encountered in and left behind when that drift was removed. At the lowest point in the pit a prospect hole has been dug some feet deeper (how much is not apparent since it is filled with water and is now a small pond). The material taken out has been piled nearby. It is found to contain abundant limestone pebbles, but this comes from below the gummy stuff and the layer of sand and is neither the Iowan nor the clay used for the brick. It is probably Kansan drift. The foreman volunteered the information that the clay which they used contained no lime but that they got in their prospect lower down contained limestone pebbles and hence was not desirable.

In the west pit the Iowan drift is only about 2 ft. thick. Then comes a horizon of bluish-grayish brown gummy clay with lenses and patches of gray sand. The thickness of this is about 3 feet to the floor of the pit. The floor of the pit is a layer of grayish sand which is not desirable and avoided. Below this as shown in the other pit is another drift containing limestone pebbles.

MITCHELL COUNTY.

About eight miles west of Osage (Rock township, Township 98 North, Range 18 West, section 34, middle of west line) a boring on a low slope penetrated mottled gray and yellow, dense, sticky clay with few pebbles. This clay suggests the super-Kansan "gumbo" rather than the normal weathered till. Five feet down this becomes sandy and wet.

A few miles to the north in section 11 (south line of the southeast quarter), a boring on the extensive flat plain showed:

DRIFT WEST OF MITCHELL, IOWA.

		Feet.
2.	Clay humus, black	1½-2
1.	"Gumbo," dense, sticky, gray, noncalcareous clay containing few small pebbles	8

Near the underlying limestone the clay is yellowish in color. A cut on a short steep slope a short distance east of this, and about three miles west of Mitchell, together with a boring, penetrated nine feet of "gumbo," dense, tough, rubber-like, brownish, noncalcareous clay. There is no overlying till (Iowan) at these places but drift pebbles and bowlders scattered over the surface show that the "gumbo" has been overridden by later ice.

One mile north of Mitchell (Mitchell township, Township 98 North, Range 17 West, section 5, west line of the southeast quarter), a boring on the flat upland plain (at 1190± feet above sea level) penetrated, beneath two feet of dark loesslike loam, the same dark brown to gray, dense, noncalcareous "gumbo" clay, rusty in spots, to a depth of nine feet. There is here no overlying till, only drift pebbles and scattered bowlders one to three feet in diameter. Two miles east of Mitchell (section 11, west line of the southwest quarter) the same dense brown clay, with "buckshot" of MnO_2, was found by boring beneath five and one-half feet of loess and one and one-half feet of sand.

At another place about five miles northeast of Mitchell (near the northeast corner of section 1) a boring on the flat plain revealed:

DRIFT NORTHEAST OF MITCHELL, IOWA.

		Feet.
3.	Humus, black clay	1½
2.	Clay, gray, loesslike, no pebbles excepting at bottom	1
1.	"Gumbo," dense, brownish gray, noncalcareous clay, sandy at bottom	5½

Again, a boring one and one-half miles east of St. Ansgar (at 1170± feet above sea level) showed:

DRIFT EAST OF ST. ANSGAR, IOWA.

		Feet.
3.	Soil, black, and loess	1
2.	Clay, sandy, brown, with some pebbles (possibly Iowan drift)	2
1.	"Gumbo," dense, sticky, gray to brown, noncalcareous clay with scattered small chert pebbles and sand grains	4½

This becomes light buff in color at the bottom near the underlying limestone. There appears to be but little glacial drift of any kind at these places. The nearly flat plain may be part of the original Kansan upland, which escaped erosion and on which the conditions for "gumbo" development existed.

WORTH COUNTY.

In borings at two points in the southeastern part of Worth county on the plain east of Manly, there was penetrated very dense, brownish to gray clay, noncalcareous, and containing few small pebbles. This suggests the "gumbo"-like clay found farther east in Mitchell county, and may really be the long weathered upper part of the Kansan till with no overlying Iowan drift. A short distance from one of these places, that is, in the low slope just east of Manly, fresh-looking till containing limestone and other pebbles was thrown out in digging a ditch. This may be the Iowan.

CERRO GORDO COUNTY.

In the western part of the Iowan area, at several places on the gently undulating, little-dissected plains of Cerro Gordo county, the auger penetrated very dense, noncalcareous clay, in most cases gray or drab colored, in some cases brownish. This clay contains few or no pebbles and suggests the super-Kansan "gumbo." It is unlike the ordinary weathered upper part of the Kansan till or of the Iowan till. In places this grades down into clay which is of similar color and texture but is calcareous and contains limestone and other pebbles, which indicates that it is till. It might be that the character of the clay here is due to the incorporation of much material from the underlying Lime Creek shale.

FRANKLIN COUNTY.

Several miles southeast of Hampton there is a loess-mantled, bulky ridge between Squaw and Haynes creeks. This may be a remnant of an old divide on the Kansan drift plain. A cut and boring near the crest of the ridge (Geneva township, Township 91 North, Range 19 West, section 7, northwest quarter) (at 1200 ± feet above sea level) showed:

DRIFT SOUTHEAST OF HAMPTON, IOWA.

	Feet.
Soil	1
Till (Iowan?), loose, yellow, leached	2
Clay, "gumbo"-like, lense, dark brown, sticky, noncalcareous and with coarse sand grains or small pebbles in lower part	6
Dark brown sandy material (decayed limestone?)	1
Limestone.	

Two miles southwest of Faulkner (Osceola township, Township 90 North, Range 19 West, near southwest corner of section 17) three feet of dense, gray, noncalcareous "gumbo" is exposed in the slope beside the schoolhouse (1140 ± feet above sea level) below thin pebbly till. This is near the foot of the slope which marks the margin of the Wisconsin drift. It is thus impossible to say whether the thin pebbly till above the "gumbo" is Iowan or Wisconsin.

TAMA COUNTY.

There are several exposures of "gumbo" in Tama county, but the interpretation to be placed upon them is, at present, somewhat problematical. The exposures are in tracts where much dissection has occurred so that it is possible the overlying till, where such is present, may be Kansan instead of Iowan till. At one exposure there is no overlying till and the "gumbo" may be regarded as super-Kansan.

About four miles northwest of Toledo, near the middle of the east half of section 7 (Township 83 North, Range 15 West), gray, noncalcareous "gumbo," spotted with red at the top, outcrops beneath the loess, in the west-facing slope, about twenty-five feet below the top. Beneath is leached, brown till (Kansan?). Between two and three miles northeast of Gladstone (Otter Creek township, Township 83 North, Range 14 West, line section 22) the Chicago, Milwaukee & St. Paul railway cut just east of the viaducts affords an interesting exposure of the following deposits (figure 7):

DRIFT NORTHEAST OF GLADSTONE, IOWA.

	Feet.
4. Loess, buff, leached for four feet, gray in lower part where thickest and contains $CaCO_3$ concretions	5-10
3. Upper till, oxidized brownish in upper part and with distinct pebble band at top, leached for three feet, highly calcareous below, with $CaCO_3$ concretions	3- 6

2. Clay, "gumbo," dense, gray, noncalcareous and containing scattered small pebbles. Upper surface uneven as though eroded or disturbed by the overriding ice................ 3- 6
1. Lower till, oxidized brownish for ten feet ±, highly calcareous to base of "gumbo." This grades downward into gray to dark slate-colored till full of $CaCO_3$ concretions; exposed 15

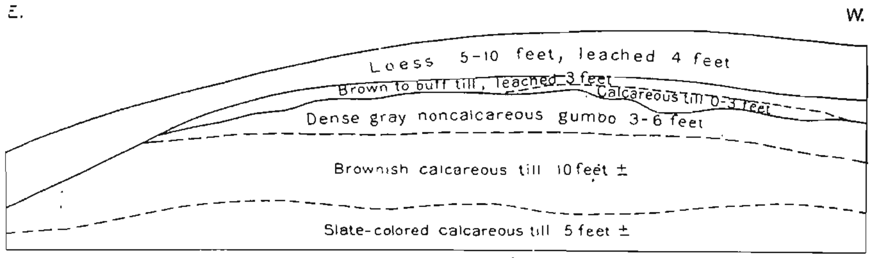


Fig. 7.—Diagram of drift exposed in Chicago, Milwaukee & St. Paul railway cut northeast of Gladstone, Iowa.

There is gradation between No. 1 and No. 2. Numbers 2 and 3 were cut away at both sides by erosion prior to the deposition of the loess. The latter mantles the crest and slopes of this spur of the upland. Estimates of pebbles from the upper and the lower tills show no marked difference in lithology.

About a mile northeast of this place (in Otter Creek township, section 11, near the southeast corner) dense, dark gray gumbo, mottled with red in the upper part, was seen exposed beneath five to ten feet of loess and still farther northeast a road cut just south of the middle of section 1 exposed the following:

DRIFT NORTHWEST OF VINING, IOWA.

	Feet.
Loess	5-6
"Gumbo," dense, brownish gray, tough and noncalcareous......	5
Till (Kansan?), brown, leached, exposed in slope..............	7

Between four and five miles north of the railroad cut and about three miles northwest of the exposure last noted above (in a slope one-fourth mile south of the schoolhouse on the east line of section 33, Carroll township, Township 84 North, Range 14 West) gray gumbo was exposed twenty-five to thirty feet above the bottom of the till slope. This has a thickness of at least five feet, as was determined by boring; it appears to grade into the till below and is overlain by thin brownish till. At levels six and ten feet higher up the gumbo is slightly exposed in patches surrounded by till as though it outcrops through holes in an overlapping thin mantle of till.

Some of the other cuts in Carroll and Otter Creek townships show a distinct reddish brown ferretto at the top of the till and beneath the loess. At these places and at those where the top of the till is less highly oxidized, the "gumbo" and upper till are not seen, evidently because of their removal prior to the deposition of the loess. These exposures in Tama county are in a belt of country five to twelve miles wide which lies north of Iowa river valley and west of Salt creek valley, and in which a notable amount of erosion was accomplished prior to the deposition of the loess. Most of this area has been mapped as outside the limit of the Iowan drift and there is good reason for regarding it as such. The presence, however, of an upper till overlying the gumbo in the exposures in Otter Creek and southern Carroll townships raises the question whether the Iowan ice may not have extended as far south as Iowa river valley. Is the succession to be regarded as:

Loess
Till (Iowan)
"Gumbo"
Till (Kansan)

or, as in Carroll county:

Loess
Till (Kansan)
"Gumbo"
Till (pre-Kansan)

The same question is raised by conditions observed about twelve miles farther north. Seven or eight miles west of Traer (Grant township, Township 86 North, Range 15 West, section 33, near middle of south line) a road cut on the steep slope of a ravine tributary to Four-Mile creek exposed the following, when seen in September, 1915:

Drift West of Traer, Iowa.

		Feet.
6.	Loess, buff to grayish	20
5.	Till, rusty brown and very stony at top	5-10
4.	"Gumbo," dense, sticky, gray, noncalcareous clay	.:4

3.	Till, gray, crumbly and full of arkosic material as from disintegrated granite	2
2.	Till, brown, leached	4
1.	Till, brown, highly calcareous.	

There is gradation from No. 1 to No. 2, from No. 2 to No. 3 and from No. 3 to No. 4. A boring sunk through the lower four feet of No. 5 into No. 4 showed that the "gumbo" really extends back into the hill beneath the upper till. Between two and three miles farther east on the north side of Wolf creek valley there is, beneath ten feet of loess, a dark ferretto at the top of the leached till. A little lower down the valley gumbo is exposed but it appears not to extend into the hill. At one place the gumbo itself is red. Unfortunately there was insufficient time, when this exposure was found, to determine what were the real relations, as they were not clearly shown in the cut.

The country bordering Wolf and Four-Mile creeks west of Traer has a maturely dissected topography with seventy to one hundred feet of relief, in contrast with the little-eroded, gently undulating topography immediately to the north and south, so that there is the same question as to whether the succession is:

Loess
Till (Iowan)
"Gumbo"
Till (Kansan)

or:

Loess
Till (Kansan)
"Gumbo"
Till (pre-Kansan)

The question concerning the interpretation of the age of the deposits in these Tama county exposures arises from the fact of their occurring in tracts where the amount of erosion which has been accomplished since the deposition of the upper till is considerably more than that generally seen in the Iowan area and about the same as that in the Kansan area south of Iowa river. Further, in several new cuts along the line of the Chicago, Milwaukee & St. Paul Railway west of the area of the Des Moines lobe in southern Carroll county and southeastern Crawford county, a well developed bed of similar dense, gray, non-calcareous "gumbo" lies between two highly calcareous till sheets. Here the general relations and the large amount of erosion which has been accomplished since the deposition of the upper till indicate that the latter is of Kansan age. If this be correct, there is clearly a pre-Kansan (or super-Nebraskan) "gumbo" as well as a super-Kansan "gumbo."[9a] As indicated above, the relations are much the same in Tama county, so that, for the present at least, final judgment as to these latter exposures must be suspended.

The question may be asked, "If there is evidence of a pre-Kansan bed of "gumbo" why may not the "gumbo" at all the exposures cited above be of pre-Kansan age and the overlying till in the Iowan area be Kansan?" In answer to this it may be said that the wide distribution of "gumbo" on top of the Kansan drift in southern Iowa and its general absence from the surface of the uppermost till in the Iowan area, excepting near Mitchell, makes it much more probable that the upper till in the Iowan area is post-Kansan and that the underlying "gumbo" is super-Kansan. Then too the moderate amount of modification by weathering and the small amount of erosion of the uppermost till of the Iowan area, taken as a whole, seems to the writers evidence that the latter till is younger than Kansan. The different lines of evidence support each other.

While it may be necessary to withhold judgment concerning some of the occurrences cited above, it seems to the writers that there remains a body of definite evidence indicating that there really is a distinct super-Kansan "gumbo" and a post-Kansan drift in the Iowan area.

[9a]Kay, G. F., Pleistocene deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geological Survey, Vol. XXVI, pp. 213-231.

CHAPTER IV

OTHER EVIDENCES OF POST-KANSAN GLACIATION.

General Character

Besides the lines of evidence which already have been presented and those which are to follow, certain phenomena have been noted which, though susceptible of various interpretations and not conclusive in themselves, are, in a way, corroborative and lend support to the foregoing conclusion. These include descriptions of some exposures of Iowan drift and logs of wells taken from the reports of the Iowa Geological Survey and from W J McGee's paper on northeastern Iowa, which may be presented together in this chapter.

In the course of the present investigation an effort was made to examine most of the exposures to which definite reference had been made in the published papers as showing Iowan till distinguishable from older deposits. Some of the old exposures are now so badly slumped and overgrown that no accurate determination of the deposits can be made. Most of those seen were unsatisfactory. Some of the old exposures and some of the new ones are suggestive. Taken by themselves most of them are of very slight value as evidence of post-Kansan glaciation. A few, such as the cut in Johnson county, are important. They embrace occurrences of till over silt or loess; of two tills with an intervening soil; till over weathered gravel; till over more weathered till; till with apparent intermixture of older "gumbo" or other deposits.

For readiness of reference, these are presented somewhat in detail in the form of notes.

Notes on certain other supposed occurrences of Iowan drift may be found in Appendix C.

WINNESHIEK COUNTY.

A boring at a point about five miles southwest of Ridgeway (in Sumner township, Township 88 North, Range 10 West, section 4, west line of the northwest quarter), showed the following:

DRIFT SOUTHWEST OF RIDGEWAY, IOWA.

		Feet.
3.	Till (Iowan?), yellow, leached	3
2.	Silt, loesslike, grayish, leached	3
1.	Till (Kansan?), leached for one foot, calcareous below.	

HOWARD COUNTY.

Professor Calvin[10] described the section exposed in a cut on the Chicago Great Western railway south of Elma, as follows:

A deep railway cut one and a half miles south of Elma reveals the Kansan drift in its unweathered phase. A few rods north of a wagon bridge which here spans the cut, the section shows:

		Feet.
3.	Yellow, unweathered Iowan till	6
2.	Old peaty soil developed in the intervals between the Kansan and the Iowan stages of glaciation	2
1.	Blue unweathered Kansan to bottom of the cut	15

There is here no ferretto zone at the surface of the Kansan; the organic material of the peaty soil bed was capable of more than counter-balancing any effects of oxidation which might have taken place before the Kansan surface was covered and protected from further change by the deposition of the Iowan drift.

CHICKASAW COUNTY.

In July, 1907, R. T. Chamberlin examined the cuts southeast of New Hampton on the Chicago Great Western railway. At the gravel pit one-fourth mile southeast of the station, overlying ten feet of rusty red-brown sand and gravel at the south end of the exposure, he found "nearly two feet of a yellow-brown, non-calcareous drift, presumably Iowan, since there are Iowan bowlders on the surface of the hillside." The following also is from his notes:

Half a mile from the station at the overhead bridge is a cut nearly 20 feet deep where the steam shovel has been within a year or two. This cut is through a ridge so that the level of the tracks is slightly higher than the top of the gravel in the pits just mentioned (Top of both gravels appear same height). The section here is:

		Feet.
1.	Iowan drift	4-8
2.	Buchanan [gravel], interglacial	1-4
3.	Kansan, brown above, but chiefly bluish till	6-7
4.	Aftonian sands and gravels, upper eight inches cemented with $CaCO_3$. Below this non-consolidated and easily dug. Upper part at about the level of the tracks. Thickness exposed by digging a little into the talus	3

[10]Iowa Geological Survey, Vol. XIII, p. 63.

The bottom of the ditch is here several feet below the level of the tracks. The Iowan is here noncalcareous, yellow brown, and stands well as a cliff face. The Buchanan is very variable. In some places there is a distinct soil line at its top. Throughout most of the cut it contains layers of clean yellow sand and generally free from pebbles. In some places this is very soft; elsewhere it has been cemented into a true sand stone. Interbedded in some places are clayey layers. Where the Kansan and Aftonian are best exposed the Buchanan loses its chief characteristics, being represented here by altered streaky sandy and clayey till.

The upper portion of the Kansan becomes brownish but the greater part is bluish. It is calcareous throughout. The Aftonian resembles that at Afton Junction closely.

See tables (Appendix A) for estimates of pebbles from these various deposits.

The cuts were examined in 1914 by the present writers. At the gravel pit Mr. Leighton found:

DRIFT SOUTHEAST OF NEW HAMPTON, IOWA.

	Feet.
Clay, yellow, with occasional pebbles	2
Gravel and sand, yellowish brown to reddish brown, cross-bedded, leached of all calcareous material, granites, greenstone and dolerites much decomposed. Clay ironstones present	20

The railroad cut at the viaduct was too badly obscured by vegetation and slumping for accurate determination except in the upper part.

BUCHANAN COUNTY.

An exposure frequently mentioned in connection with discussions of the Iowan drift is the old gravel pit near Doris on the Illinois Central railroad, about four miles east of Independence (Byron township, Township 89 North, Range 8 West, section 32, northwest quarter). This was Doctor Calvin's type exposure of Buchanan gravel, if not also of Iowan till. The exposure is almost wholly obscured by slumping and vegetation. Trees up to eight inches in diameter have grown in the bottom of the excavation and the banks are mostly grassed. On the north side, when the pit was visited by the present writers in 1914, there had been some recent excavation for road gravel so that the upper till and the underlying gravel were well exposed through a space about fifty yards in extent. The following was seen below the level of the gently undulating bowlder-strewn Iowan plain:

DRIFT AT ILLINOIS CENTRAL RAILROAD GRAVEL PIT, DORIS, IOWA.

		Feet.
3.	Soil, dark	½-1
2.	Till, dense, hard, jointed and leached, dull yellowish, pebbly. No limestone pebbles seen	3 -6
1.	Gravel, rusty brown, ferruginous, pebbles small to eight inches in diameter, largely of polished quartz and chert with some disintegrating granites	3

In two places stringers of gravel run up into the till and in one place the till extends down one and one-half feet into a depression in the gravel. The deposit overlying the gravel is clearly glacial till and the only question is that of its age. The gravel as originally exposed is reported to extend down to a depth of twenty feet below the base of the upper till and to be underlain by dense bluish till.

In September, 1907, this pit was visited by T. C. and R. T. Chamberlin. The following is from the notes of the latter:

From Independence we drove east to see the famous cut along the I. C. R. R. tracks three miles east of the town. This is the type locality for the Iowan drift. On the way out there we saw sloughs and slight hummocky bunches which cause a slight unevenness in the regular slopes. The topography looks young—almost Wisconsin in places.

The cut is just west of Doris station and has been used extensively for gravel. The pit shows Buchanan gravels capped by 0-6 feet of a fresher appearing yellowish till which closely resembles the upper yellow till at Oelwein. It is a brighter colored material than is usual in the oxidized part of the Kansan, but it contains more Fe_2O_3 apparently for the shades are deeper than the yellow gray Kansan upper zone. The upper part is non-calcareous as is the till at Oelwein, but the lower portion is calcareous. Leaching has gone down about 4 feet.

Below this till are the Buchanan gravels which is the material sought for the railroad. They are considerably oxidized but contain inclusions of till. Fifty pebbles dug from the Iowan drift at this gravel pit were classified. (See Table No. III, Appendix A.)

The striking feature of this set of pebbles is the old and weathered condition of the igneous rocks and the great proportion of polished quartz and chert pebbles. The granites were crumbly while the greenstones generally were incased in thick weathered zones. The mica schist was very rotten.

The highly polished quartz and chert pebbles were of the type usually assigned to pre-glacial deposits. They may have been subject to wind polishing while resting upon the surface of the older drift, while the Iowan glacier was advancing. However, some of the other quartz pebbles were sub-angular and not polished at all though they might have been buried beneath the surface.

On the whole it looks as though the Iowan ice had merely scraped up the surface portion of the older drift and that these old and weathered pebbles received most of their weathering before incorporated in the Iowan drift.

The idea of the Iowan being "calcareous to the grass roots" is not supported at Independence nor at any other point where I have seen this drift. Its darker color compared with the fresh yellow Kansan may be due to the fact that some of the oxidized ferretto material has been mixed with scrapings of the yellow till. The Buchanan gravels below looked older than the Iowan.

The relations of the Iowan till to the older deposits are illustrated by the following cited by Doctor Calvin[11]:

A very common relation of Pleistocene deposits is illustrated by the well section on land of J. W. Welch, in the southwest quarter of section 28, Buffalo township. The record shows,

		Feet.
3.	Dark soil and yellow till	4
2.	Reddish ferruginous sand and gravel	23
1.	Blue clay, penetrated	1

No. 1 of this section is Kansan drift, No. 2 is Buchanan gravel, and No. 3 is Iowan till. In the same quarter section another well shows:

		Feet.
3.	Soil and yellow till	22
2.	Reddish gravel	11
1.	Blue clay, with pockets of sand	19

Concerning the relations at the Doris gravel pit Doctor Calvin wrote[12]:

The gravel rests on typical Kansan blue clay and is overlain by yellow Iowan till which varies from less than a foot in thickness at the western end of the exposure to more than six feet at the extreme eastern end. Two facts are at once apparent; first,

[11]Iowa Geological Survey, Vol. VIII, pp. 239-240, 1897.
[12]Op. cit., p. 242.

the gravel is interglacial in position; second, it is very old as compared with the overlying Iowan till.

LINN COUNTY.

Cuts along the newly graded line of the Waterloo, Cedar Falls & Northern electric railway afforded numerous clean exposures of the upper part of the drift. In one of these, northwest of Marion (Monroe township, Township 84 North, Range 8 West, section 4, southwest quarter), there is a suggestion of overriding by a readvance of the ice. There seems to be a mixture of leached and calcareous till. The till (Iowan?) at A (figure 8) is highly calcareous below a leached zone three feet in

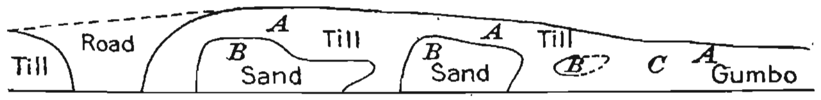


Fig. 8.—Diagram of cut on Waterloo, Cedar Falls & Northern Electric railway, northwest of Marion, Iowa, showing relations of Iowan (?) till to dune sand (B B) and "gumbo" (C) super-Kansan?.

thickness. At B. B. are two pockets of fine sand with dimensions of six by ten feet, which resembles dune sand, and at C is dense, noncalcareous, gray clay with small pebbles. This resembles the super-Kansan "gumbo." While the deposits suggest overriding by a readvance of the ice, the relations are not sufficiently clear to make sure that there is more than one till sheet. So also with the next cut in the northwest quarter of section 4, which shows:

DRIFT ON WATERLOO, CEDAR FALLS & NORTHERN RAILWAY, NORTHWEST OF MARION, IOWA.

		Feet.
7.	Loam, sandy	1-2
6.	Gravel, rusty, in layers and pockets	0-2
5.	Till (Iowan?), brown, leached	2-3
4.	Till (Iowan?), brown, calcareous	2-3
3.	Sand	1-2
2.	Clay, brown to gray, partly leached, partly calcareous. This grades down into	1-3
1.	Clay (Kansan?), dense, dark, slate-colored, pebbly till. In one place below a black strip, possibly a remnant of an old soil, this clay is greenish and calcareous	1±

There is more or less mixing and the relations are not so clear and simple as the above might seem to indicate.

And again at the viaduct in Otter Creek township (Township 85 North, Range 7 West, section 29, northeast quarter) is the following:

Drift on Waterloo, Cedar Falls & Northern Railway, Six Miles Southeast of Center Point, Iowa.

		Feet.
4.	Dune sand, stratified	5-12
3.	Till (Iowan?), light buff, pebbly, leached	3
2.	Till, similar to above (Iowan?), calcareous	1
1.	Till (Kansan), dense, brown, calcareous, of different texture from No. 2 and with a fairly distinct line of division	0- 4

On the washed surface of the lower till (No. 1) are small, brown, pebble-like masses of clay one-fourth to one half inch long which can be crushed with the fingers. They suggest "buckshot" or ferruginous concretions seen in some of the glacial clays. They are not seen in the upper till, Nos. 2 and 3.

JONES COUNTY.

The large cut on the Chicago, Milwaukee & St. Paul railway about two miles east of Martelle, (Greenfield township, Township 83 North, Range 4 West, section 9) affords the interesting exposure illustrated in figure 9.

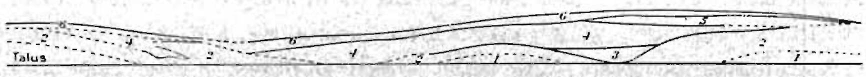


Fig. 9.—Diagram of cut on Chicago, Milwaukee & St. Paul railway east of Martelle, Iowa, showing relations of Kansan till (1 and 2); gray clay (3); Buchanan (?) gravel (4); Iowan (?) till (5); loess (6).

The generalized section is as follows:

Drift on Chicago, Milwaukee & St. Paul Railway, Two Miles East of Martelle, Iowa.

		Feet.
6.	Clay (loess), pebbleless, thicker in sag than over the swells	1- 5
5.	Till (Iowan?), lens-shaped bed, buff to gray, leached, pebbly	0- 5
4.	Sand, buff to brown, over rusty gravel (Buchanan?)	0-10
3.	In a buried sag which the cut crosses obliquely is gray clay, noncalcareous and not well bedded in the upper part ("gumbo"-like), and laminated and calcareous below (Yarmouth?)	0- 8
2.	Till (Kansan), buff, leached 3-5 feet, calcareous below; exposed	1-15
1.	Till (Kansan), calcareous, gray on dry face, dark slate-colored where moist; exposed	1-10

In places at the top of No. 2 is a limy crust or a line of concretions composed of the calcium carbonate leached from No. 3. The thin upper bed of till (No. 5) suggests a readvance of the ice after the deposition and weathering of the sand and gravel and the correlations indicated may perhaps be made.

Professor Calvin[13] gives the following log of a well bored on the gently undulating plain at a point three or four miles north of Martelle (Fairview township, Township 84 North, Range 4 West, section 20, near center). The log is said to be typical of a very large number of wells in this county.

LOG OF WELL ONE-HALF MILE SOUTHWEST OF FAIRVIEW, IOWA.

		Feet.
5.	Loam or vegetable mould, black	1
4.	Clay, yellow, of Iowan stage	8
3.	Dark brownish band, upper portion of Kansan stage	4
2.	Blue unoxidized portion of Kansan stage	12
1.	Sand in which occurs an abundance of water	4

JOHNSON COUNTY.

One of the most significant exposures seen was the first cut north of Iowa river on the electric railroad about thirteen miles northwest of Iowa City (Jefferson township, Township 81 North, Range 7 West, section 2, southeast quarter). This was examined by Mr. Alden in 1905, and in 1912, 1913 and 1914 by Mr. Leighton who has published views and a description of the exposure[14]. The cut is in the lower slope seventy or eighty feet below the highest part of the ridge to the north and its base is not over thirty feet above the river.

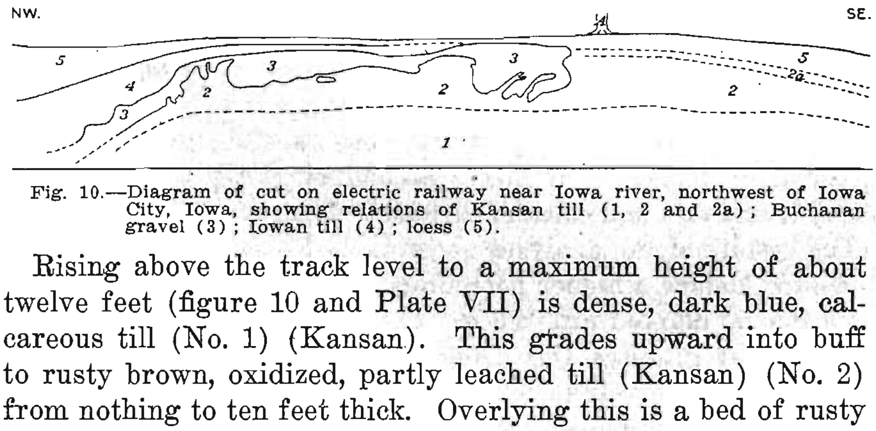


Fig. 10.—Diagram of cut on electric railway near Iowa river, northwest of Iowa City, Iowa, showing relations of Kansan till (1, 2 and 2a); Buchanan gravel (3); Iowan till (4); loess (5).

Rising above the track level to a maximum height of about twelve feet (figure 10 and Plate VII) is dense, dark blue, calcareous till (No. 1) (Kansan). This grades upward into buff to rusty brown, oxidized, partly leached till (Kansan) (No. 2) from nothing to ten feet thick. Overlying this is a bed of rusty brown gravel (Buchanan) (No. 3) which is partly cemented by iron oxide and in which the crystalline pebbles, which range in

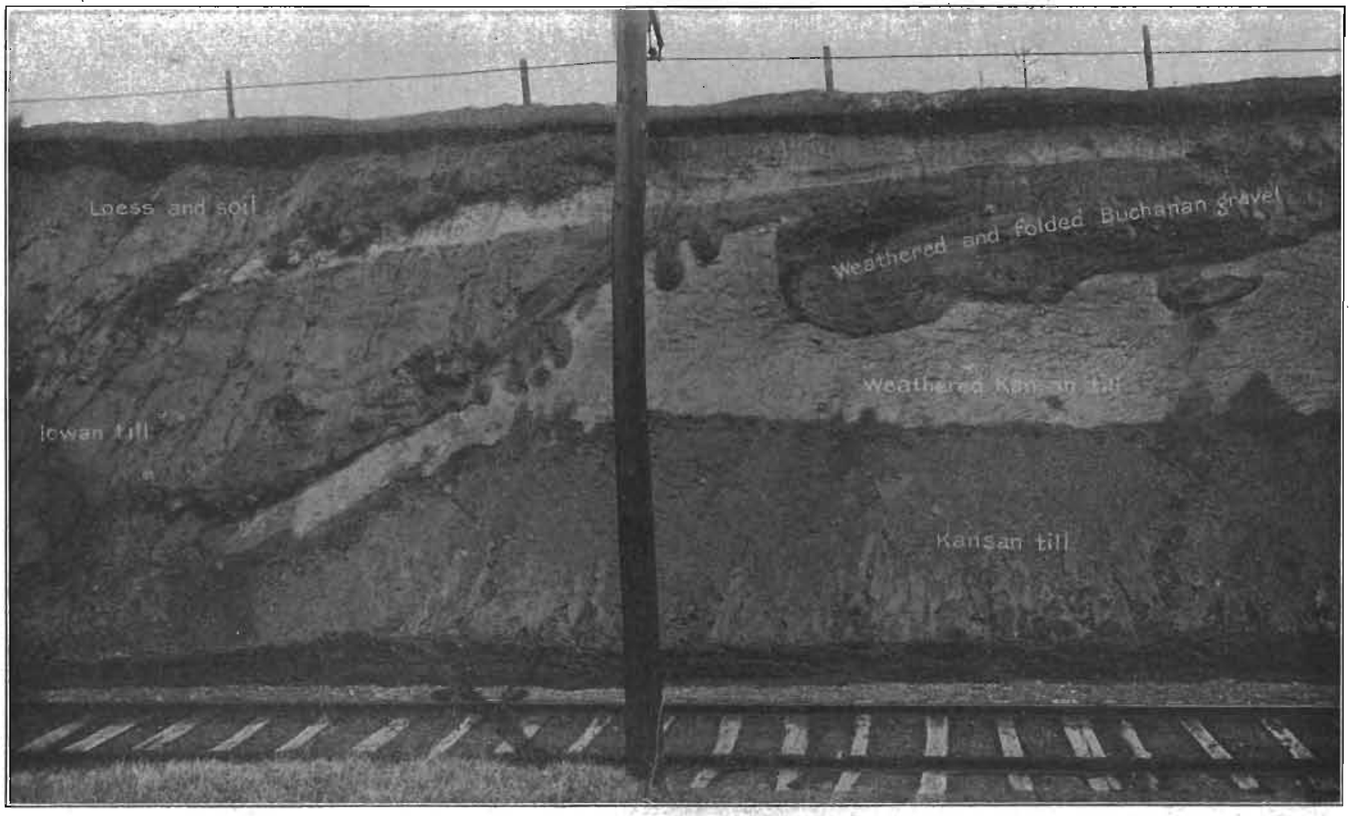
[13]Iowa Geological Survey, Vol. V, p. 65, 1895.

[14]Leighton, M. M., An exposure showing post-Kansan glaciation near Iowa City, Iowa: Jour. Geology, Vol. 21, pp. 431-435, 1913. The Pleistocene history of Iowa river valley, north and west of Iowa City in Johnson County: Iowa Geological Survey, Vol. XXV, (1914) pp. 142-146, 1916.

size up to one foot in diameter but are mostly less than three inches, are much decayed. The gravel bed is contorted and folded as if by pressure from the northwest. One of the synclinal folds is seven feet deep. Overlying the gravel is yellowish, blue-streaked till (Iowan) (No. 4) two to four feet thick across the summit and attaining a thickness of at least eight feet along the west monoclinal limb. This till is highly calcareous excepting in the upper few feet where it is leached. Yellow fossiliferous loess (No. 5) lies on the northwest slope and loess and sand occur on the southeast or riverward slope.

This cut was reëxamined by Mr. Alden in June, 1915, and again in September, the last time in company with R. D. Salisbury, Frank Leverett, and George F. Kay. Beneath the southeast slope of the hill, in the lower end of the cut the relations are not entirely clear but there is here, below the loess, a thin bed of bluish gray clay (No. 2a) similar to the super-Kansan "gumbo." This rises westward in the section on top of the rusty jointed and weathered lower till (No. 2). Just below the trees, this is covered by only three feet of loess and soil. Immediately west of the trees (A) the crumpled bed of gravel shown in Plate VII comes in and the "gumbo" clay disappears. The crumpled condition of the weathered gravel bed and the presence of the overlying fresher till appears to be good evidence of a post-Kansan readvance of the ice at this place. The upper till, gravel, and lower till were carefully examined and pebbles collected from each. Secondary constituents, such as clay ironstones and calcium carbonate concretions were avoided. The results of the analyses as given in tables II, IV, V of Appendix A show a higher percentage of greenstones in the upper till but no marked difference. The gravels have a higher percentage of granites and a lower percentage of limestone and dolomite than either till.

Thirteen or fourteen miles southeast of this place in the first cut west of the river on the electric railroad at Iowa City (West Lucas township, Township 79 North, Range 6 West, section 9), there is exposed dense, dark, slate-colored till, regarded by Doctor Calvin as Kansan, and overlying it is rusty red gravel (Buchanan) twelve feet thick. Above the gravel is twenty-five



View of cut on interurban railway northwest of Iowa City, Iowa.

feet of loess. This is about five miles southeast of what is regarded as the limit reached by the Iowan ice sheet. The absence of a till overlying the gravel and the undisturbed character of the deeply weathered gravel in this cut are in striking contrast with the conditions found in the cut in Jefferson township described above.

CHAPTER V

BOWLDERS.

Bowlders in the Iowan Area

Character and size—Discussions by former investigators of the Iowan drift have given prominence to the presence of notably large granite bowlders scattered over much of the Iowan drift, and these have been regarded as particularly characteristic of the Iowan drift.

These bowlders are dominantly coarse-grained granites, either light gray or pink, some so coarse that the term pegmatite is applicable. Basic rocks, greenstones, and quartzites are much less common and are not generally so large as the granites. Among the latter diameters of ten to twenty-five feet are common, and some measure as much as thirty-five, forty, or even fifty feet. The largest one known is in Floyd county, Riverton township, in the northwest quarter of the southwest quarter of section 22 (Plate VIII A). Its dimensions are fifty by forty by eleven and one-half feet above ground. A smaller piece which lies beside it and apparently is a fragment of the larger, measures seventeen by seven by one and one-half feet.

As a rule, the granites show some effects of surficial weathering, such as rounding of their angles and exfoliating shells. A few are badly decomposed, but most of them are far from being in an advanced state of decay. Slight accumulations of arkosic material lie in cracks and cavities, but otherwise most of the bowlders are relatively sound.

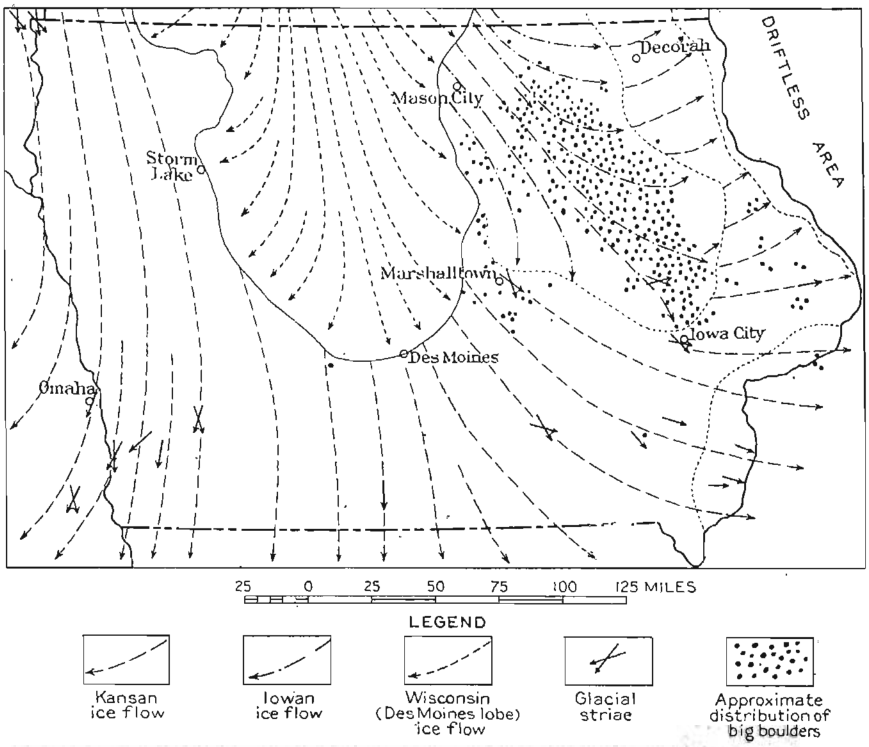


Fig. 11.—Diagram showing the distribution of big granite bowlders as related to probable directions of movement of ice sheets in Iowa.

Geographic Distribution—The big bowlders are most numerous in a broad belt, or bowlder train, extending southeastward in what was probably the zone of axial flow of the Iowan ice through Mitchell, Floyd, Chickasaw, southwestern Fayette, Bremer, northeastern Black Hawk, Buchanan, northeastern Benton, and Linn counties (figure 11). Not only are many large ones to be seen here, but smaller bowlders are numerous also, and are being used for foundations of buildings and, rarely, are piled as stone fences. Many of the smaller bowlders and some large ones are scattered both east and west of the main belt. In the southwestern part of the area bowlders, especially large ones, are much less numerous. In this part one may travel several miles without seeing more than a very few bowlders perhaps two or three feet in diameter, and then suddenly may come upon a huge one.

A. Large Iowan bowlder in Floyd County, Iowa.

B. Vertical face of loess in railway cutting near Bertram, Iowa.

Topographic Distribution—Some writers have described these bowlders as being confined principally to swales, or depressions in the slopes, and from this it has been inferred by some that most of the bowlders are the residue left on the removal of considerable drift by erosion when the broad open swales were being formed. It is true that most of the bowlders left scattered on the land at the present time lie in these swales, yet the writers' observations show that many erratics, both large and small, do occur on the uplands as well as in swales. This leads them to the opinion that originally the bowlders were scattered indiscriminately over uplands, slopes and swales. Since the region has been occupied by white men, however, nearly all the bowlders have been gathered from the tracts desired for cultivation, both in order to clear the land and in order to use the stone for foundations of buildings and abutments for bridges. Over a large part of the area the ground water level is so high that except in the driest seasons water seeps out of the lower slopes and in the bottoms of the shallow swales. These tracts, being wet lands, are not generally cultivated but are reserved as pastures for stock, and the farmers have not taken the trouble to remove the bowlders therefrom; hence at present most of the scattered bowlders lie in the swales. The typical Iowan topography is apparently not due primarily to erosion since the last ice disappeared from the area, but is the result of mantling of an older mature erosion topography with a post-Kansan sheet of drift. It thus appears that the bowlders in the swales can not be regarded as the residuum of a much eroded drift sheet, and their presence in the swales can not be regarded as evidence of much erosion. Most of the bowlders evidently were left by the melting ice on the surface of the drift where they lay before man began his collection of them. Some are wholly or partly buried in the drift.

Doctor Calvin and others have shown that some of these bowlders have beveled surfaces and bear glacial striations, and thus show that they were transported, for a time at least, in the basal part of the ice. Such striations were observed by the writers also. It is probable that the striations on many bowlders have been obscured by etching and exfoliation, inasmuch as the striæ seen are in most cases on surfaces which have been but recently uncovered by excavation.

Character of the Embedding Till.—Borings were made by the side of several partly buried big bowlders to determine the character of the embedding drift. These showed that the drift is the same yellow, moderately weathered till, which is leached to depths of three to five feet, as seen in most of the exposures, and which is regarded as Iowan.

Bowlders in the Kansan Area

There seems to have been a general impression that the large granite bowlders in Iowa are strictly confined to the Iowan drift area.[15] Indeed, the presence of large granite bowlders in some outlying tracts has been taken to indicate the presence of Iowan drift. The supposed lobe of Iowan drift in southwestern Tama county was mapped partly because of the presence of such bowlders[16]. And in Jasper county, in certain townships which have the aspects of Kansan topography, the occurrence of one bowlder with a diameter of thirty feet and of other large ones of granitic composition led Mr. I. A. Williams to postulate an extension of the Iowan ice into that area to explain their presence[17].

It appears, however, that occasional large granite bowlders occur farther south in Iowa, some of them remote from the Iowan drift area (figure 11). Several erratics with diameters of ten to thirty feet have been reported from Lucas county.[18] In section 32 of Center township, Wapello county, A. G. Leonard found a fine-grained granite measuring six by twelve by five feet[19]. J. A. Udden reports finding in section 15 of Walnut township, Jefferson county,[20] a porphyritic granite seventeen by twelve by seven feet in size. Besides these some granites ten feet in diameter were noted in Henry county.[21]

During the present investigation several other large bowlders were seen in the Kansan area. Of these, three were in Marshall

[15]Calvin, Samuel, The Iowan drift: Jour. Geology, Vol. XIX, p. 599, 1911.
[16]Savage, T. E., Iowa Geological Survey, Vol. XIII, p. 200, 1903.
[17]Iowa Geological Survey, Vol. XV, pp. 288-290, 1905.
[18]Kay, G. F., in a personal communication.
[19]Iowa Geological Survey, Vol. XII. p. 439, 1902.
[20]Iowa Geological Survey. Vol. XII, p. 358, 1902.
[21]Savage, T. E., Iowa Geological Survey, Vol. XII, p. 420, 1902.

county; one in Logan township in the southeast quarter of section 4, which measured ten by four by six feet; one in the central part of section 8, Eden township, which measured fifteen by fifteen by three feet; and one in the southwest quarter of section 33, Timber creek township, which measured eight by five by three feet. In Jasper county a bowlder with a diameter of ten feet was seen protruding from a cut on the Chicago, Rock Island and Pacific railway, six miles east of Kellogg. In Cedar county, in the northwest quarter of section 21, Gower township, another bowlder with a diameter of ten feet was found. McGee reported[22] other large bowlders as occurring near Davenport, Iowa. Big bowlders also occur in the northwest and southwest parts of Jackson county, near Epworth in Dubuque county, and in Clinton county, at places to which it is doubtful if the Iowan ice extended.

Professor Savage[23] also reports considerable numbers of bowlders as occurring northeast of Maquoketa in Jackson county. "Many of these," he states, "are of exceptionally large size for drift of their age (Kansan), the larger masses having a diameter of six to nine feet."

Big Bowlders As Evidence of Iowan Glaciation

Inasmuch as large granite bowlders occur outside the Iowan drift area, it is apparent that some such bowlders were carried by the Kansan drift There is, therefore, some question as to how far the big bowlders within the supposed limits of the Iowan drift can be regarded as evidence of a distinct post-Kansan ice invasion.

In this connection it is well to consider the direction of movement of the Kansan ice which spread over the eastern half of the state (figure 11). Several observations of glacial striæ have been noted. In 1914 striæ were found on limestone underlying the Kansan drift at Kuhnle's quarry at Charles City, Floyd county, trending south-southeast. Professor S. W. Beyer[24] observed striæ in Marshall county, in LeGrand and Timber Creek townships, trending south 20° to 25° east. Professor W. H.

[22]U. S. Geol. Survey Eleventh Ann. Rept., p. 482.
[23]Savage, T. E., Iowa Geological Survey, Vol. XVI, p. 634, 1906.
[24]Iowa Geological Survey, Vol. VII, pp. 239-240, 1897.

Norton[25] found two sets of striæ at the quarry one and one-fourth miles northeast of Quarry Station (Section 1, LeGrand township, Township 83 North, Range 17 West); one bearing south 22° east to south 47° east; the other, south 35° to 64° west. Dr. H. F. Bain[26] reports the observation of striæ at Eddyville near the south line of Mahaska county. These consisted of an earlier set trending south 42° east and a later set trending south 70° east. Doctor J. A. Udden[27] observed obscure striæ northeast of Perlee in northeastern Jefferson county. The trends are given as south 35° east, and south 75° west. Possibly the direction of movement making the latter may have been north 75° east, since so westerly a direction of movement at this place of either the Kansan or pre-Kansan ice seems rather doubtful, while local northeasterly deflection is quite possible.

At Brighton in southwestern Washington county striæ reported by H. F. Bain[28] trend south 4° to 6° east with a few scratches south 6° west to south 4° east. Not far away on Crooked creek striæ were seen trending south 67° east. In a paper "Glacial scorings in Iowa," C. R. Keyes[29] cites observations of striæ near Iowa City, as reported by McGee, Calvin, and others, trending south 52° to 62° east. Striæ trending south 70° to 73° east were observed also near the western end of the electric railway bridge at Iowa City by W. C. Alden.

W. H. Norton[30] discovered striæ at an old cut on the Chicago, Milwaukee & St. Paul railway five miles northwest of Cedar Rapids, Linn county, (one mile west of Linn Junction) ranging south 79° east to east 14° north.

In 1915 W. C. Alden observed a finely glaciated ledge recently exposed in grading a road six miles east of Delmar, Clinton county (Waterford township, Township 83 North, Range 4 East, section 21, southeast quarter). Here the striæ trend east 10° north.

[25]Iowa Acad. Science, Vol. 18, pp. 80-83, 1911.
[26]Iowa Geological Survey, Vol. IV, p. 343, 1895.
[27]Iowa Geological Survey, Vol. XII, p. 431, 1902.
[28]Iowa Geological Survey, Vol. V, p. 155, 1896.
[29]Iowa Geological Survey, Vol. III. pp. 148-165, 1894.
[30]Iowa Acad. Science, Vol. 18, pp. 80-83, 1911.

Somewhat doubtful striæ bearing east 43° north were seen by the writers on a limestone ledge in the road at a point about one mile southwest of Monticello, Jones county (Monticello township, Township 86 North, Range 3 West, section 33, northeast quarter).

If these several striæ, or even most of them, were made by the Kansan ice, as seems probable since most of them are outside the area of the Iowan drift, they show something as to the direction of the ice flow reaching these parts of Iowa. If one may judge from these as well as from general consideration of the eastern limit of the drift in northeastern Iowa, the Kansan ice in the eastern half of the lobe which invaded Iowa radiated eastward, the directions of flow shifting from south 20° or 25° east in Marshall county,to south 70° to 73° east in Johnson county, east 10° north in northern Clinton county, and thence in northeastern Iowa also toward the east. Ice currents crossing Johnson county thus must have swung eastward to the vicinity of Muscatine and Davenport. Thus the main stream of Kansan ice which crossed northeastern Iowa where are now most of the big bowlders, probably did not reach the Kansan area south of the Iowan drift boundary. Some big bowlders certainly were carried by the Kansan ice. If only that part of the ice flow which spread over northeastern Iowa crossed the ledges yielding most of the massive blocks of granite, the distribution of the big bowlders would be such as we now find it to be even had there been no post-Kansan ice invasion. The big bowlders of southern Iowa are few but it was also noted that the big bowlders are much less abundant in the southern part of the Iowan drift area west of Linn county than farther north, so that if such bowlders were carried by the Kansan ice it might be expected that but few would be seen in the Kansan area west, southwest, and south of Johnson county.

Judging from their distribution alone, therefore, it would seem that the big Iowan bowlders could just about as well be referred to transportation and deposition by the Kansan ice as by the post-Kansan glacier. The writers are therefore not inclined to place very much weight on these erratics, taken by themselves, as evidence of a distinct post-Kansan glaciation of northeastern Iowa. It is, however, a notable fact that by far the larger part of the big bowlders of Iowa, probably 99 per cent of them, occur within the supposed limits of the Iowan drift, and taken in connection with the other evidence they may be said to support the theory of a post-Kansan glaciation.

CHAPTER VI.

IOWAN OUTWASH AND OTHER GRAVELS.

In accordance with the evidence already presented which indicates that there really is an Iowan drift-sheet, it would be expected that outwash gravels of post-Kansan and pre-Wisconsin age would be found in valleys which received the drainage from the Iowan ice.

VALLEY TRAIN TERRACES.

In practically all of the valleys of northeastern Iowa there are gravel deposits. A few of the valleys head in the area of the Wisconsin drift and much of the gravel in these probably is Wisconsin outwash. The rest of the valleys, however, head in the Iowan drift area and much of the gravel in these probably is Iowan outwash.

It may be well to give some details as to the occurrences of gravels near and outside of the limit of the Iowan drift. These deposits were carefully examined at many places. None of the valleys was studied throughout its full extent and the relations to the gravel deposits on Mississippi river have not been determined.

Starting at the north in Howard county, a gravel terrace was observed fifteen to twenty feet above Upper Iowa river at and west of Florenceville, Iowa, and Grainger, Minnesota. Near the state line a cut south of the bridge showed coarse gravelly material composed mostly of limestone fragments, partly angular and partly waterworn, with some intermingled crystalline pebbles, but the gravels here appeared more like the material of a local alluvial fan than glacial outwash. Ten Mile creek heads in a broad open swale east of Ridgeway. At the point where the

Iowan drift boundary has been mapped as crossing, the valley narrows sharply and the stream enters a gorge between bluffs of shale. One would expect to find here a well-marked deposit of gravel washed out from the Iowan ice front, but none was noted in the two or three miles traversed.

There is some development of a terrace in the Upper Iowa river valley above Decorah, but this was not examined. Well marked terraces occur at points below this place. About a mile north of Freeport interesting exposures of old drift and of fresher gravel were seen. The relations are shown in figure 12.

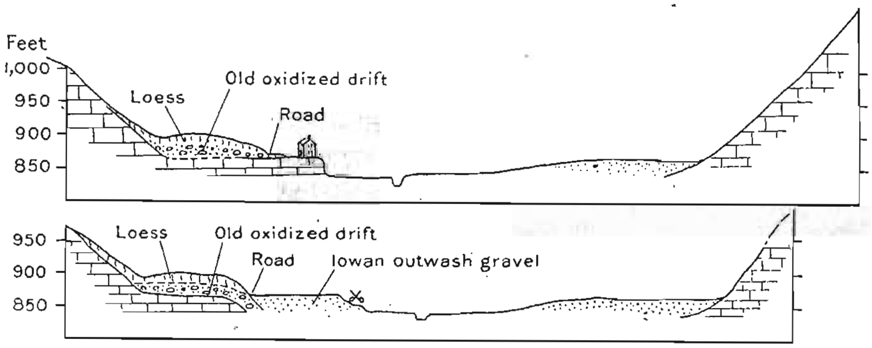


Fig. 12.—Diagram showing terraces on Upper Iowa river near Freeport, Iowa. Loess (1); old weathered drift (Kansan?) (2); outwash gravel from Iowan drift (3); limestone (4).

At this place (Decorah township, Township 98 North, Range 8 West, section 12, southwest quarter) A. M. Sheets has a gravel pit in a remnant of a terrace just below the road. The stratified sand and gravel exposed here (eight feet) are fresh, clean, and unoxidized. The pebbles are largely of limestone with intermingled cherts, quartzites and crystallines. It seems probable that this fresh-looking gravel is outwash to be correlated with the Iowan stage of glaciation. The house stands on a terrace just south of the road at about the same level, but underlain by limestone and sandstone. Just west of the house and above the terrace, deeply weathered red gravelly drift is exposed in the road cut. No limestone pebbles were found in this, only cherts, quartzites and dense fine-grained crystallines. It is probable that this is at least as old as the Kansan stage, as is also that on top of the bluff near the Freeport bridge. Farther down the valley in Glenwood township, (Township 98

North, Range 7 West) limestone gravels were seen at several points, notably at the new dam and powerhouse in section 8.

Doctor Calvin[31] describes these gravels, referring to them as "deposits of uncertain age, probably Kansan." He writes, "Along the river from the county line westward, in the southeast quarter of section 36, Pleasant township, the terraces are well developed. Not far from the line the stratified terrace materials have been undercut by the river so as to show a fresh section forty feet in height. Near and below the middle of the section there are many coarse blocks from the Oneota and Saint Peter formations, but the main body of the deposit consists of rounded fragments of chert and local limestone, with some pebbles of quartz, diorite, granite and other northern crystallines, all embedded in quartz sand. Some small streaks made up almost exclusively of northern pebbles and quartz sand are iron stained and resemble the ordinary Buchanan gravels. Between section 36 of Pleasant township and section 16 of Decorah, there are many remnants of the same terrace deposits." Doctor Calvin regarded only the deposits of fresh clean sand, such as that on the southeast side of the valley northeast of Freeport, as outwash from the Iowan ice.

There is a gravel terrace on North Branch of Turkey river south of Cresco (section 2, New Oregon township), fifteen feet above the stream. Similar deposits were also seen at points farther down stream in Winneshiek county, west and southwest of Ridgeway. Four miles south of this place (Sumner township, Township 97 North, Range 10 West, section 11, northeast quarter) the sand and gravel terrace stands twenty feet above the stream. At and near Spillville is a fifteen-foot gravel terrace. Below this the valley is largely a narrow winding gorge. Remnants of the terrace were seen down to and below Fort Atkinson. This place stands on a bench which appears to be underlain by gravel. About two miles farther southeast and one and one-half miles west of Festina, the gravel terrace is well developed near the bridge. Twenty feet above the present flood plain an exposure in the cut bank showed two feet of brown loamy soil overlying the gravel from which the lime-

[31]Iowa Geological Survey, Vol. XVI, p. 124.

stone pebbles had been removed by solution to a depth of six feet (that is, eight feet from the surface). Below this the gravel contains plenty of waterworn pebbles of limestone and some angular fragments. Gravels head in some of the tributaries on the west, but one is somewhat surprised not to see them more markedly developed in situations where there were such direct lines of drainage from the Iowan ice front.

The streams at and near Waucoma are bordered by a gravel terrace about twelve feet above the flood plain. At one point where an examination was made no limestone pebbles were noted within eight feet of the surface. In Fayette county a terrace is well preserved above, at and below Eldorado, in which the gravel is largely composed of limestone pebbles. Near the bridge in section 35, Dover Township (Township 95 North, Range 8 West), this bench stands about thirty feet above the stream and there are plenty of limestone pebbles with the crystallines. There is also a large terrace remnant at the east line of the township. The towns of Clermont and Elgin stand on broad remnants of this terrace. The Chicago, Rock Island & Pacific Railway has a large pit in the well stratified gravels north of Elgin. At the latter place the terrace is about twenty feet above the broad flood plain. Where they were examined near the cemetery, the gravels are rusty in the upper part, but the crystalline pebbles are fresh and sound and limestone pebbles were plentiful below five feet from the surface.

In his report on Fayette county[32] Prof. T. E. Savage referred the deposition of these gravels to waters from the Kansan ice sheet. Those seen by the writers, however, appear quite fresh enough to be correlated with the Iowan stage of glaciation. In his recent volume on the Pleistocene Mammals of Iowa[33] Dr. O. P. Hay makes the following reference to these gravels:

Near Clermont. In Nettie C. Anderson's list, page 28, Prof. T. E. Savage reported a mastodon tooth from near Clermont, which was in the possession of Mr. C. E. Allen, of Clermont. Mr. Allen has sent the writer a drawing which shows that the tooth is that of Elephas, probably *Elephas primigenius*. Professor Savage has kindly informed the writer that the tooth

[32] Iowa Geological Survey, Vol. XV, pp. 451-53.
[33] Iowa Geological Survey, Vol. XXIII, pp. 433 and 434, 1913.

came from materials filling the valley of Turkey river. He believes that these were deposited during the melting of the Wisconsin ice-sheet. If this is true, the animal which bore the tooth lived at the close of the Wisconsin stage or afterwards. Near this same place was found a part of a skull of the musk-ox *Ovibos moschatus.* Mr. Allen states that the tooth was taken out of the gravel pit of the Rock Island Railway between Clermont and Elgin, Iowa, and that it was found at a depth of about twenty feet. The tooth, or what remains of it, is in the possession of Mr. Allen.

The present writers regard this gravel as of Iowan rather than Wisconsin age. The terrace is reported by Prof. A. G. Leonard[34] to be fifty-five feet above the stream at Elkader, where much of the town east of the river is built upon it, and at Osterdock it is sixty feet above the river.

The valley of Otter creek between West Union and Elgin was not examined for outwash gravels.

Volga river, a tributary of Turkey river, receives drainage from the Iowan area from the vicinity of West Union to Edgewood in southwestern Clayton county. The lower part of Fayette is built on a well marked terrace ten to fifteen feet above this stream and below the bench on which stands Upper Iowa University. At the mouth of this branch of the valley at Albany is a broad gravel terrace.

At and above Wadena the gravel terrace is twenty-five to thirty feet above the stream. The main part of Volga stands on a terrace of fine gravel which occupies a broad abandoned channel surrounding the low hill on which is the cemetery. West of town a pit in the edge of the terrace showed three feet of sand over five feet of sand and fine iron stained calcareous gravel. This terrace is twenty or thirty feet above the present stream.

The tributaries from the south have a fall of 300 to 400 feet in distances of three to six miles between the border of the Iowan drift and Volga river. They are in sharply cut valleys which, so far as was seen, do not contain outwash deposits. They were not, however, carefully examined. From a point about three miles east of Greeley, Delaware county, southeast

[34]Iowa Geological Survey, Vol. XVI, pp. 287-288.

nearly to Dyersville the drainage is toward rather than away from what has been mapped as the Iowan border.

A gravel terrace stands twelve to twenty feet above the streams just north and northwest of Dyersville, also south of this place and at Worthington. With these may belong the terrace gravels seen on the same stream at Fulton and Hurstville, north of Maquoketa in Jackson county.

Well preserved remnants of terrace gravels were examined at many places along Maquoketa river from Manchester to Maquoketa. The former place is built upon a broad flat beneath which wells penetrate as much as forty feet of gravel, an amount sufficient to divert the river over limestone ledges. Southeast to Hopkinton the terrace stands twenty to twenty-five feet above the stream. The gravels are well exposed at the mouth of the gorge traversed by Lime creek and also west of the point where this stream enters the gorge on its way down from the upland. Doctor Calvin[35] in describing the terrace states that "excavations show that the main body of this terrace is made up of very old, weathered, ferruginous material of the age of the Buchanan gravels"; also:

It is interesting to note that the terraces observed in this county are nearly all referable to the period of ice melting following the invasion of the Kansan glaciers. In some cases there have been some additions to the terrace deposits in times more recent than the Buchanan gravels, but the significant point is that these valleys are pre-Kansan in origin.

The gravels where seen by the present writers seem not too old to be regarded as Iowan, while other evidence cited above (page 71) seems to show that the valley cut in the limestone is itself of post-Kansan rather than pre-Kansan age, at least in the part examined.

Four miles south of Lime creek, only the upper leached part of the gravel was seen.

At and north of Monticello the terrace is well preserved. Exposures show the gravels to be well stratified and cross-bedded. They are noncalcareous, partly fresh and partly rusty. Though the gorge below Monticello is narrow and winding remnants of the terrace were noted at many points. The pebbles

[35]Iowa Geological Survey, Vol. VIII, p. 176.

in the sand are mostly fine but range in size up to eight or ten inches; the crystalline pebbles are mostly sound and hard, not much decomposed. But few limestone pebbles were found. The village of Canton at the east line of Jones county stands on a bit of this terrace.

A terrace near Newport is well preserved and north of Olin on Wapsipinicon river, and at the bridge between Hale and Oxford is a terrace of fine sand and gravel twelve to thirteen feet above the stream.

Rochester, on Cedar river south of Tipton, stands on a gravel terrace, but not much attention was given to deposits along this stream. Some of these, such as those on the broad flat opposite and above Cedar Bluff, may have resulted from slackwater during the Illinoian stage. Such slackwater must have occupied the valley as far up as Ivanhoe bridge southwest of Mount Vernon.

In the Iowa river valley, below the North Liberty lobe, there are terrace remnants of probable Iowan age. It does not seem likely that these are Wisconsin, since terraces of that age play out before reaching Marshalltown and since the terraces to which reference is here made are mere remnants at the bends of the stream. A similar terrace on Pardieu creek about four miles north of Iowa City (Penn township, Township 80 North, Range 6 West, section 29) is regarded by Mr. Leighton as composed of outwash from the North Liberty lobe of the Iowan ice.[36]

The gravels distributed **along** the courses of the streams within the Iowan area, but which do not head in the Wisconsin drift area, were probably deposited by the outflowing waters as the margin of the Iowan ice sheet retreated across the area during the final stage of melting. Such gravels are well developed in the Wapsipinicon river valley at Central City, Linn county, at Quasqueton, Buchanan county, and east of New Hampton, Chickasaw county; in the Little Cedar river valley at Bassett, Chickasaw county, at Stacyville, Mitchell county, and in the valleys of numerous small streams.

State of weathering.—As noted above, these gravels are unconsolidated and moderately fresh in appearance. Decayed

[36]Leighton, M. M., Additional evidences of Post-Kansan glaciation in Johnson County, Iowa: Proc. Iowa Acad. Sci., Vol. 20, pp. 251-256, 1913.

pebbles and whole ironstone concretions are comparatively few, though there are numerous fragments of ironstone concretions, as if these had been derived from such older gravel-bodies as the Buchanan. The amount of solution which the limestone pebbles have suffered is considerable. This varies according to the coarseness of the material. Fine sandy gravel commonly contains no limestone pebbles in the upper ten to twelve feet, whereas in coarser materials calcareous constituents have been removed to depths of three to five feet. Gravel of the latter sort was exposed in the Chicago, Anamosa & Northern Railway pit near the depot in Quasqueton, Buchanan county, on a terrace of Wapsipinicon river. The upper three to four feet of the gravel contain cherts, greenstones, granites, dense igneous rocks, and quartz, with no limestone, whereas below there are many irregular fragments of limestone as large as four to six inches.

In Chickasaw county, one mile west of Bassett, the Chicago, Milwaukee & St. Paul Railway has a large gravel pit nearly fifteen feet deep in a well developed terrace bordering Little Cedar river. The gravel consists mostly of pebbles half an inch to an inch and a half in diameter. The limestone constituents seem to have been removed by solution to depths of eight to twelve feet from the surface.

THE ABSENCE OF GLACIO-FLUVIAL GRAVEL IN CERTAIN VALLEYS OF THE KANSAN AREA.

It appears from the literature of the Kansan drift of southern Iowa that there is a general absence of gravel terraces from that area. So far as the present writers have had opportunity to examine the valleys this seems to be true of those which do not reach into areas of younger drift. This opposes an interpretation which regards the gravels described above as due to increased erosion of drift on the slopes and deposition in the valleys during the Wisconsin stage or at any other post-Kansan time. The lack of erosional details on the slopes of the Iowan drift also opposes this view. These gravel terraces are, therefore, regarded by the present writers as composed of glacial outwash of Iowan age.

UPLAND GRAVEL.

Two phases of upland gravel were found throughout the Iowan area, which appear to be of two distinct ages: Kansan and Iowan.

Iowan Kames.—Reference is elsewhere made to the occurrence of morainal knolls of relatively fresh gravel in Winneshiek county. Besides these, knolls of similar material were seen in Howard county, Sumner township, in the east-central part of section 5 and the west-central part of section 4; and in Mitchell county, Cedar township, in the northwest quarter and northeast quarter of section 5. Deposits of upland gravel, not in distinct knolls and showing moderate weathering, were also examined in Linn county, Jackson township, central part of section 21, and in Delaware county, Oneida township, west line of the southwest quarter of the northwest quarter of section 12. Limestone pebbles are present in most of these below depths of three to five feet. Comparison of the amount of weathering of the upland gravels and of the gravel terraces of the Iowan area, taking into consideration their topographic positions, indicates that the gravels are probably of the same age.

Kansan Kames.—At many places in the Iowan area, and especially in Buchanan county near Independence, there are low rounded knolls on the upland which apparently belong to an older deposit. These knolls contain highly oxidized and decayed ferruginous gravels, with an abundance of ironstone concretions and disintegrated granites, greenstones, and other igneous rocks. The surfaces of some of the quartzites even show etching. Calcareous material is generally lacking, having been removed by solution. Everywhere the gravels have a distinct brown color, and in all respects show great age. The materials range in size from sand to small bowlders a foot in diameter. The smaller pebbles, and many of the larger ones, can readily be cut in two by a chisel-edged hammer. These gravels are better for road-metal than those of the Iowan or Wisconsin terraces, as their more advanced state of decay permits them to pack well. Professor Calvin called these deposits Buchanan gravels and considered them as having been deposited as the Kansan ice sheet was melting away. Since they occur as knolls on the upland, it appears that they are of the nature of kames. Some of the knolls are thinly mantled with younger drift (Iowan).

COMPARISON WITH GRAVELS OF WISCONSIN AGE.

Wisconsin valley-train gravels were examined somewhat in Cerro Gordo, Floyd, Franklin, and Hardin counties. The amount of leaching of these is much less than in those of the Iowan terrace gravels and other alteration is less also. Limestone pebbles occur up to the soil or within two feet of the surface. The erosion of the Wisconsin terraces is also considerably less. There can be little question but that the gravels here regarded as Iowan are older than those washed out from the Des Moines lobe of the Wisconsin stage.

SUMMARY.

The chief facts which were noted in the field regarding the gravel phenomena are:

1. Terraces of glacio-fluvial gravel occur in all the major valleys in the Iowan area and continue for some distance beyond the limit of the Iowan into the Kansan drift area. Those in the Wapsipinicon, Maquoketa, Volga, Little Turkey, Turkey, Upper Iowa, Little Cedar, and certain smaller valleys have no other source than the Iowan area.

2. So far as noted valleys in the Kansan area which do not head in areas of younger drift do not contain gravel terraces.

3. The sand and gravel of the Iowan terraces are moderately weathered.

4. Some small gravel knolls occur in connection with local morainic features of the Iowan area. The materials of these are weathered similarly to the Iowan terrace gravels.

5. Here and there in the Iowan drift area there are low rounded knolls of much-decayed gravels (Buchanan). These gravels are probably of Kansan age. Some of them are mantled with the later drift.

6. The Iowan gravels are considerably more weathered and eroded than the Wisconsin gravels.

These facts support the theory that an ice sheet invaded northeastern Iowa at a time considerably later than the Kansan and some time prior to the incursion of the Des Moines lobe of the Wisconsin ice sheet.

CHAPTER VII

THE LOESS AND ITS SIGNIFICANCE.

One cannot work in the area of the Iowan drift or adjacent areas of older drift without being confronted with the problem of the loess. The writers did not undertake an exhaustive study of the various deposits of loess but some observations were made which have direct bearing on the main question under investigation. Deposits of loess known to be of pre-Iowan or of post-Wisconsin age are not included in the following discussion, excepting as specifically indicated. This does, however, refer to the main body of loess in the Upper Mississippi valley region.

GENERAL CHARACTERS.

Earlier students have shown that the constituents of the main body of loess of the Upper Mississippi Valley are such as would be derived from glacial rock flour, that is, such as might be blown from the surface of the drift or from the flood plains of valleys draining a drift area.[37] The loess is a fine-textured, dustlike silt, buff in color as seen in most shallow exposures, and gray in the lower parts of deeper ones. Generally, when rubbed between the fingers, it feels floury. From this it varies locally to sandy and not infrequently is it found closely associated with wind-blown sand, especially in the lower part. There are also in places intercalated layers of fine sand. The writers have not observed coarse sand or pebbles included in what they would regard as undisputed loess. In parts of many clean exposures there is a more or less definite banding or semblance of stratification, usually conforming to the surface or slope on which the deposit lies. A sort of flakiness also has been noted, suggesting stratification, but clear-cut lamination, so characteristic of glaciolacustrine silts, is rarely if ever seen; so also definite cross-bedding is comparatively rare and such as is seen suggests eolian rather than stream deposition. There are also faint dark colored lines here and there which may be the residue of carbon from vegetation buried during the deposition of the loess.

[37]Chamberlin, T. C., and Salisbury, R. D., Preliminary paper on the driftless area of the Upper Mississippi Valley: U. S. Geol. Survey Sixth Ann. Rept., pp. 281-283, 304-305, 1885. Chamberlin, T. C., Supplementary hypothesis respecting the origin of the loess of the Mississippi Valley: Jour. Geology, Vol. V, pp. 794-802, 1897.

One of the notable characteristics of the loess when it is dry is vertical cleavage (Plate VIII B). Unprotected, nearly vertical faces will stand for years without slumping and even retain for a long time marks of the excavator or "jack-knife carved initial." This peculiarity probably results from homogeneity of texture and interlocking of the minute angular particles of which it is composed, combined, perhaps, with incipient cementation by iron oxide or calcium carbonate as the result of alternate wetting and drying.

The loess bordering and overlapping the Iowan drift area is rarely thicker than thirty feet and in most places there is less than fifteen feet.

THE FOSSIL CONTENT AND ITS SIGNIFICANCE.

In many places the calcareous part of the loess contains small shells. These vary in size from tiny spirals to shells half an inch or more in length. In some places they are numerous, in others moderately so, in still others rare or absent.

Professor Bohumil Shimek, of the University of Iowa, has made an extensive study of the character, composition, relations and fossils of the loess and has published his results in a long list of papers covering a period of twenty-five years. The chief points of significance to which he has called attention in these several papers[38] are: (1) the shells are preponderantly of land snails; (2) they are identical in most cases with those of snails now inhabiting damp, shady places and feeding on vegetation in the same localities; (3) the small percentage of fresh-water forms which are found are similar to those which now live in seepy places on slopes and in ponds; (4) many of the shells are fragile, yet generally nearly perfect in their preservation.

These and other facts as to texture, composition, geographic and topographic distribution indicate, according to Professor Shimek, that the loess was deposited by wind, that the sites of deposition were clothed with vegetation, and that the climate was much like the present, in other words interglacial. He writes:[39]

[38]Shimek, B., The loess and the Lansing man: Bull. Lab. Nat. Hist., State University of Iowa, Vol. V, pp 327-346. 1899-1904. Loess and the Iowan drift: Bull. Lab. Nat. Hist., State University of Iowa. Vol. V, pp. 352-367. 1899-1904. The significance of Pleistocene mollusks: Science (New Ser.), Vol. XXXVII, pp. 501-509, 1913.

[39]Science, N. S., Vol. XXXVII, p. 508.

> The only conclusions then which can be drawn from the fossils of the loess is that during the deposition of the several loesses climatic conditions were not materially different from those which exist in various parts of the same general region today. Such differences as do exist point rather to a drier climate in the northern part of the loess-covered area than that of today.

Since no plant remains have been found in the loess, he argues that the rate of deposition was slow, so slow that the generations of trees and other plants had time to decay and their humus residue to be dissolved out before being buried to depths sufficient for preservation.

Most of the foregoing conclusions seem sound. The great predominance of land shells and the relative scarcity of aquatic forms, together with the peculiarities of its topographical distribution, have had considerable influence in leading many to an acceptance of the eolian theory of origin of the loess. It is not always possible, at least without very careful study, to determine that the loess at any given exposure has not been modified or moved since its original deposition. So it is probable that in many cases some of the textural properties of the loess as seen are due to other factors, mainly secondary, such as rehandling by slope-wash, creep and slump, some local deposition in transitory ponds, disturbance by burrowing animals, penetrating roots, and uprooting of trees, frost action, removal of soluble constituents by percolating waters and their redeposition as layers, concretions or tubules—that all of these and perhaps others have contributed to its present physical properties.

With allowance made for such factors the eolian theory of origin for the loess which borders and overlaps the Iowan drift seems to the writers to meet most, if not all, of the requirements of the case if a source of the material is available.

MODIFICATION OF THE LOESS BY WEATHERING.

Wherever thicknesses of eight feet or more of loess have been seen in cuts along the border of the Iowan drift, there is usually a gradation downward from leached to calcareous loess in the lower part. A few feet below this gradation zone the loess changes color from buff to gray. The features of an average exposure are given in the following generalized section:

GENERALIZED SECTION OF LOESS.

		Feet.
3.	Soil, black humus, changing below to brownish, no pebbles	½-1½
2.	Loess, leached, buff to yellow, does not react to acid (dilute HCl), no fossils or lime concretions in this zone; rarely 10-12 feet....................................	6-8
1.	Loess, calcareous, upper few feet buff, grayish below, includes small shells and calcareous concretions in many places. This zone is usually not seen in exposures less than eight feet deep.	

The persistence of these general characteristics in the region examined by the writers has an important significance in reading the history of the loess. Two things seem to be indicated by these phenomena: (1) That the color of the upper ten feet or more has been changed by oxidation from gray to buff or yellowish (and to brownish just below the soil); and (2) that percolating water has dissolved and removed the calcareous particles and snail shells from the upper six to eight feet or more, where they were present. If the calcareous zone is not exposed, fossil shells may not be found.

The grayish loess has been regarded by some as a distinctly older deposit than the overlying buff loess.[40] While this may be true of some of the gray or bluish gray loess described by Professor Shimek and others as occurring beneath the buff loess in places outside the Iowan drift area the writers have seen numerous exposures of buff loess grading downward into gray where the latter shows no particular evidence of greater age. In no case in the Iowan area have the writers noted any zone of leaching at the top of the gray loess and beneath calcareous buff loess, nor has such a definite, highly oxidized band been seen separating the two as Professor Shimek reports having seen in some places. The writers are inclined to regard the buff and the gray loess seen in most places in the northeastern quarter of the state as comprising respectively the oxidized and unoxidized portions of one practically continuous deposit. The general absence of shells and other calcareous material from the upper six to eight feet or more of

[40]Shimek, B., Loess and the Iowan drift: Bull. Lab. Nat. Hist. State University of Iowa, Vol. V, p. 366.

the loess, would seem to indicate either (1) that conditions during the time of deposition of this upper part of the loess were not favorable to local molluscan growth or (2) that the time since has been long enough for percolating waters to dissolve and remove the shells to the depths indicated, and that the deposition of this loess was in the main completed some time ago. So far as known to the writers there is no evidence warranting the first inference.

Leaching action would be accomplished by oxidation so that if the second deduction be correct it may be inferred that the loess was largely unoxidized and gray or bluish gray in color when deposited. In those places where deposition of loess has continued to the present time it may be that some of the last of the transported dust was derived from the leached and oxidized portions of the drift and alluvial materials and so was oxidized and noncalcareous when deposited as loess.

The above phenomena also lead one to the inference that the main mass of the loess was once calcareous, that whereas now the leached zone is probably increasing in depth there was a time when calcareous loess accumulated at a rate greater than the rate of leaching. These inferences strongly suggest a special time of loess deposition, an epoch which may be considered as having practically closed when the rate of deposition became less than the rate of leaching. Since then there has probably been relatively little loess deposited in this region excepting locally in favored situations.

DISTRIBUTION OF THE LOESS.

The loess of the region under consideration is thickest in three situations: (1) along river valleys draining from the Iowan drift area; (2) around the border of the Iowan drift, and (3) in paha.

(1). In some places the buff loess and associated sand is so thick bordering the larger streams as to form hills and ridges rising distinctly above the adjacent interstream areas. This is so noticeable along Cedar river in Linn and Johnson counties and along Wapsipinicon river in Linn and Jones counties that one is reminded of the remark of earlier geologists, that the streams left the plains to cut through the hills. An exposure in a bluff in the northwest part of Cedar Rapids shows the unusual thickness of at least fifty feet of loess, and at the Chicago & North Western Railway quarry southeast of that city there is at least thirty feet of loess overlying till and rock. In some instances the loess in such situations is sandy.

Besides these cases of conspicuous topographic effects, there are many places along valleys where the loess is thick without forming distinct ridges, and, in addition, sand dunes are to be found. The thickening of the loess along valleys is common both within and without the Iowan drift area, probably more so outside the marginal belt.

Just why the accumulation of loess should have been so marked along valleys is for the most part a question of source of supply and lodgment. It seems reasonable to refer the source of supply in large part at least to the river flats and the factors of lodgment to vegetation and topography. Northeastern Iowa was principally a prairie region at the time of settlement by white men, the timber being mostly confined to belts bordering the streams,[41] and the thicker deposits of loess are found mostly in these timbered belts. There is no question but that the arboreal vegetation would favor deposition in these tracts. The same is true of the topography. Not only would the steep slopes and ravines cause lodgment, but furthermore the reduction of the velocity of air currents sweeping up over the bluffs from the valley bottoms would result in deposition in the lee of the crests.

(2) Another situation where the loess reaches considerable thickness is around the border of the Iowan drift area. It has been mentioned that the till within this area is generally at or near the surface, and that on crossing the border to the area of the Kansan drift the loess covering becomes notably thicker, even in locations not particularly related to valleys. As distance from the Iowan border increases the thickness of the loess on the Kansan diminishes, excepting where the loess is definitely associated with valleys. Over most of the Iowan drift area loess is in general either lacking or constitutes a very

[41]See map of primeval forests and swamps by W J McGee compiled principally from original records of the U S. General Land Office, U. S. Geol. Survey Eleventh Ann. Rept., Pl. XXII, 1889-90.

thin mantle rarely attaining a thickness of three feet, excepting in the southern and southwestern parts of the area, in Benton, Tama, and Grundy counties, where thicknesses of four to six feet are common. Reference is made elsewhere to this exceptional area.

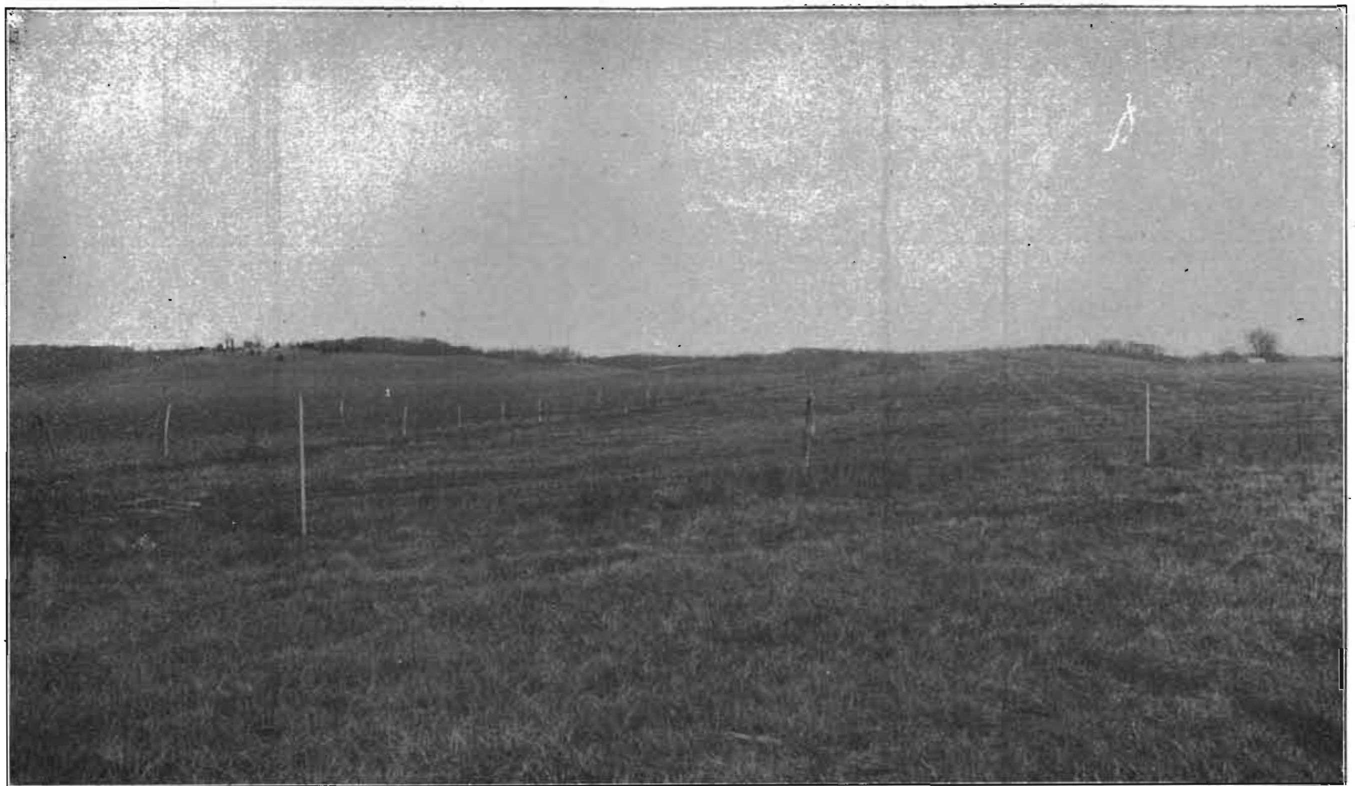
As an excellent example of the areal relations of the loess to the Iowan drift, the North Liberty plain in the northern part of Johnson county may be cited.[42]

This plain, which is four to five miles wide and about eight miles long, appears to have been covered by an extension of a lobe of the Iowan ice across Iowa river. Its longer axis trends northwest-southeast. The drift here is covered by a thin mantle of wind-blown sand and loess but at the border these deposits thicken abruptly and form a prominent line of ridges and hillocks twenty to thirty feet high. As seen from the North Liberty plain this resembles a terminal moraine (Plate IX). Exposures and auger borings in this belt, however, reveal nothing but loess and sand. There may, perhaps, be a low core of drift, but positive evidence of such is wanting. As seen from the outer side, no immediate relief is discernible, the materials simply spread out over the Kansan drift surface and mantle the slopes of the adjacent valleys, that of Iowa river on the east and that of Clear creek on the south.

The ridges on the south and southwest sides of this plain are dominantly sand, but beyond these the texture of the material changes in a short distance to that of loess and the thickness of the deposit is less. Cuts on the Interurban railway near the border of the plain which are twenty-five feet deep do not reach the bottom of the loess, whereas shallow road cuts five miles or less outside of this area expose the underlying Kansan till. These areal relations suggest that the materials of the bordering ridges were blown from the surface of the plain or from this and its westward continuation, the broad bottom of Iowa river valley in northeastern Iowa county.

Immediately south of Blairstown, in southern Benton county, loess is thin or absent from the area having the Iowan type of

[42]Leighton, M. M., Iowa Geological Survey, Vol. XXV, 1916. A full discussion of the evidences that the North Liberty plain is a part of the Iowan drift area is here given.



Loess hills and ridges bordering the North Liberty plain, Johnson County, Iowa.

topography, but it thickens abruptly at the border of this area and mantles the rugged eroded surface of the Kansan drift beyond. If the loess came from Iowa river, five miles to the south, why should it thin so suddenly at the boundary of the area having the Iowan type of topography? Possibly because the drainage conditions of the dissected Kansan drift controlled the distribution of the timber and afforded conditions more suitable for anchorage of the loess than did the smoothly undulating prairie farther north. On the other hand the reason may be that the loess was blown southward from the raw surface of the newly deposited Iowan drift in the areas which continued as prairie. The winds may have been anticyclonic, blowing from the surface of the retreating ice sheet to the north and northwest.

Within that part of the northeast border of the Iowan drift area which extends from Fort Atkinson in southwestern Winneshiek county to Dyersville in western Dubuque county, the Iowan till is generally at or near the surface, but along the border the loess thickens into knolls and ridges. Throughout much of this distance there is clearly no genetic relation between the loess border and any streams. There is, however, a close general correspondence between this border and the line between prairie on the west and timber on the east, as shown by McGee's map. In other words, the thickening of the loess along this line is explainable on the ground that the forested surface of the dissected drift to the east afforded adequate anchorage for the wind-blown material but one must look elsewhere than to adjacent valley flats for the places of derivation of the dust by prevailing westerly winds. Professors Chamberlin and Salisbury, in their study of the Driftless Area, noted that this loess thins for a distance eastward and then thickens again in the immediate vicinity of Mississippi river.[43] A corresponding change in texture is also said to take place, there being a sandy texture along the Iowan border, finer farther eastward, and then coarser again along the Mississippi.[44] Professors Calvin, Leonard, Savage, Udden, and Bain in their reports on the counties east of and including the eastern border of the

[43]U. S. Geol. Survey Sixth Ann. Rept., p. 283, 1884-1885.
[44]Ibid, p. 281.

Iowan drift area[45] refer to the thickened loess along this border as in contrast with the loess-free area to the west. Thicknesses are stated to range from a few inches to thirty feet. Professor Leonard states that the average thickness in Clayton county is not over ten feet, while Udden gives the average thickness on the Kansan drift in Clinton county as fifteen to twenty feet. All refer to it as probably, in large part at least, an accumulation of dust blown from the Iowan drift to the west.

These relations certainly strongly suggest that the loess along the east border of the Iowan drift area from Winneshiek county to Dubuque county was derived from the surface of the Iowan drift. Here again anticyclonic winds from the retreating Iowan ice sheet may have been the transporting agent.

(3) Elliptical hills and elongated ridges of loess or capped with loess, which McGee called paha,[46] are scattered over parts of the Iowan drift area, the large majority of them being concentrated in the southeastern part, in Benton, Linn, Johnson, and Jones counties.[47] McGee[48] included in the type of topography represented by the paha "the elongated swell of soft and graceful contour, standing apart on the plain or else connected with its fellows sometimes in long lines, again in congeries, and locally merging to form broad loess plateaus" (Plate X). A few are situated in the Kansan drift area, but generally not far from the Iowan border. The paha of the Iowan drift area are situated on the uplands, and in most cases away from valley flats so that it is probable that in many cases the material comprising the mantle of the loess and sand was blown from the drift-plain itself.

One of the most notable characteristics of these hills and ridges is the prevalent northwest-southeast (south 45° to 60° east) trend of their longer axes.

Their persistent southeasterly trend suggests deposition of the loess by prevailing northwesterly winds, possibly anticyclonic winds blowing from the retreating ice sheet. There are, however, certain reasons for suggesting that, in some

[45]Iowa Geol. Survey, Vols. IV, V, VIII, X, XIII, XV, XVI.

[46]U. S. Geol. Survey Eleventh Ann. Rept., pp. 220. 255, 396-414, 446-459, 1889-90.

[47]See Stanwood, Fairfax, Rock Island, Cordova, Farley and Winthrop topographic sheets.

[48]Op. Cit., p. 397.

instances at least, the direction of the wind was transverse rather than parallel to this trend, that is southwesterly, and that the trend itself is due to the orientation of drumloidal till cores.

Till was seen by the writers exposed up to thirty feet above the base of the eighty-foot north slope in the road cut on the paha ridge three miles northwest of Lowden, Cedar county. Above this level the cut, which was ten to fifteen feet deep, was wholly in loess to the top of the ridge.

Another hill, which would probably be classed as a paha, stands two miles north of Sand Spring, Delaware county. It is about one-half mile long, less than one-fourth mile wide, and its slopes rise sharply from the flat plain to a height of about fifty feet. Its long axis trends slightly south of east. A road cut at the crest of the ridge exposed seven feet of buff loess overlying four feet of leached till (apparently Kansan) with a well-marked red ferretto zone at the top.

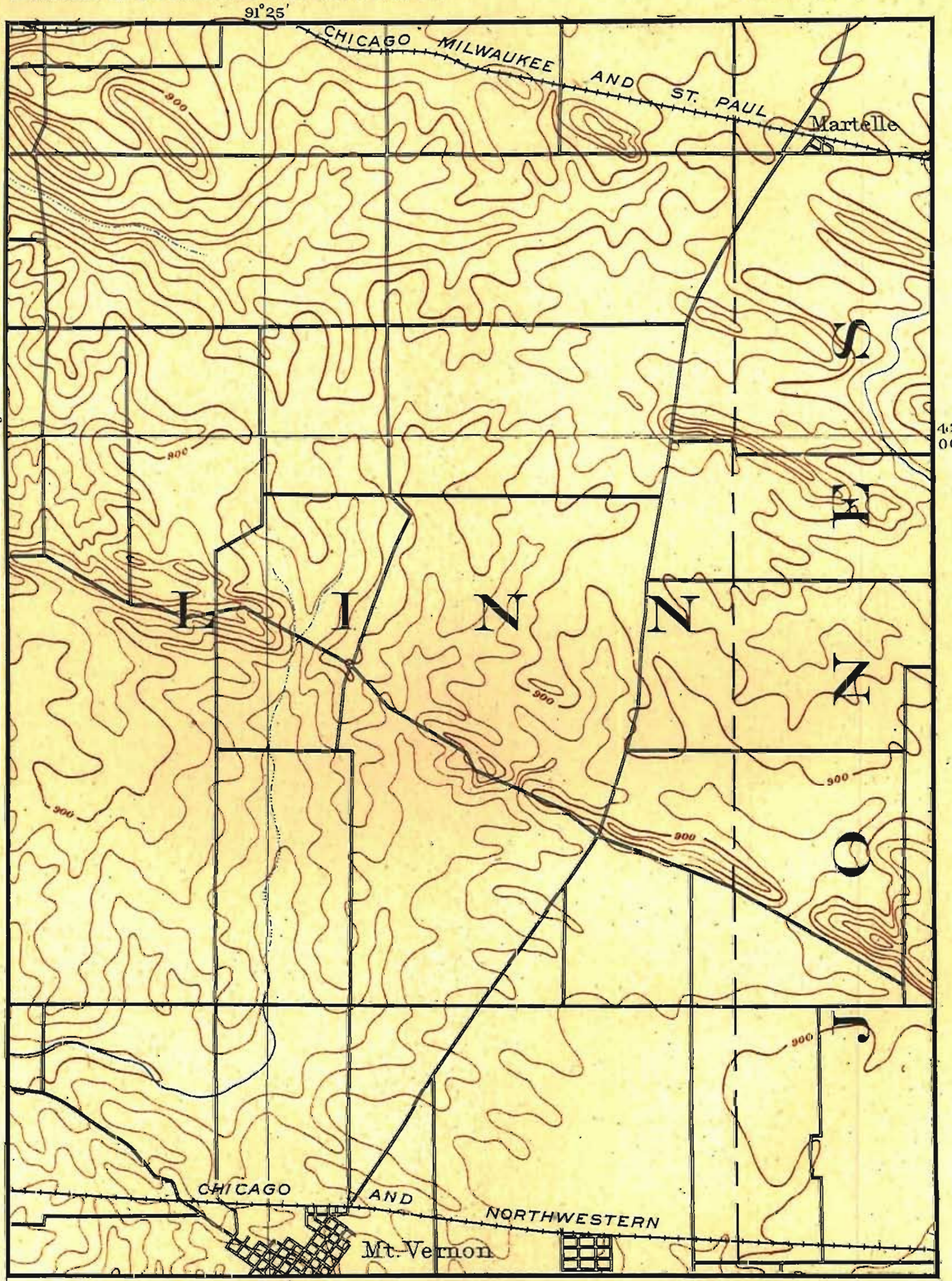
Professor Wm. H. Norton in his reports on the Geology of Linn,[49] Scott, Cedar, and Bremer counties presented considerable evidence showing that some at least of these hills have cores of glacial till and he discusses the question of the nuclear till hills being genetically related to drumlins or other forms due to the moving ice. He cites the paha in Cedar county as found in three areas.

* * * an area peripheric to the Iowan frontier, in part within the Iowan drift, and in part situated on the Kansan overlooking the Iowan plains below, and an area upon the Kansan too remote from the Iowan border to have been under the control of the glacier ice of that invasion.

Although most of the paha are in the Iowan drift area and have been regarded by several writers as in some way related to the Iowan stage of glaciation they are not wholly confined to this area and as noted above the nuclei, in some cases at least, appear to be Kansan till.

Under the eolian hypothesis, drumlins of Kansan or Iowan drift, or of both, as well as other hills, would afford suitable

[49]Iowa Geological Survey, Vol. IV, pp. 177-184, 1894; Vol. IX, 395, 1898; Vol. XI, pp. 356-366, 1900; Vol. XVI, pp. 376-386, 1905. See also T. E. Savage's report on Benton county for description of till nuclei: Iowa Geological Survey, Vol. XV, pp. 141-143.



TOPOGRAPHIC MAP OF A PORTION OF THE IOWAN DRIFT PLAIN IN LINN AND JONES COUNTIES, IOWA, SHOWING PAHA

Scale $\frac{1}{62,500}$

0 ½ 1 2 3 Miles

Contour Interval 20 feet

Datum is mean Sea level.

places for lodgment of wind-blown dust, both because of their own relief and because in many instances they were probably covered with timber. If the nuclei of the paha really are drumloidal the prevalent trend is explained as the long axes lie parallel to the known, or probable directions of the ice-movement. The thickness of the loess capping is in numerous cases fifteen or twenty feet or more.

Among the sections of paha examined by the writers were the cuts in the Norway paha described by Professor Savage[50] where there seems clearly to be a till core to the ridge. The beautifully striated limestone bowlder pictured by McGee[51] as from the loess of the Norway paha probably came originally from the till core of the ridge and was introduced into the loess by rolling or sliding down the hill slope while the loess was accumulating about it, though McGee did not so explain its presence. Writing of the foreign materials in the loess in this connection McGee states:

* * * Foreign materials are rarely found within it; in perhaps one in twenty of the sections commonly exposed in railway or roadway cuttings, cellar excavations, and roadside gullies, bowlder-like masses of drift clay, ranging from an inch to a foot or two in diameter, may be found; in one section in a hundred an erratic pebble (generally well rounded) may appear; in one section in five hundred a bowlder a foot or more in diameter may be found; and in one section of the many thousands examined a limestone bowlder, so beautifully striated as admirably to illustrate this class of icework, came to light.

Probably in most, if not all, cases the occurrence of pebbles or bowlders in the loess can be explained in a manner similar to that given above.

One relation of sand and loess to an included bowlder was very well illustrated in a cut on the interurban electric railway, one mile northwest of Bertram, Linn county, Iowa (Township 83 North, Range 6 West, north line of the northeast quarter of section 33) (figure 13). The section showed:

[50]Iowa Geol. Survey, Vol. XV, p. 142.
[51]U. S. Geol. Survey Eleventh Ann. Rept., Pl. XLVI.

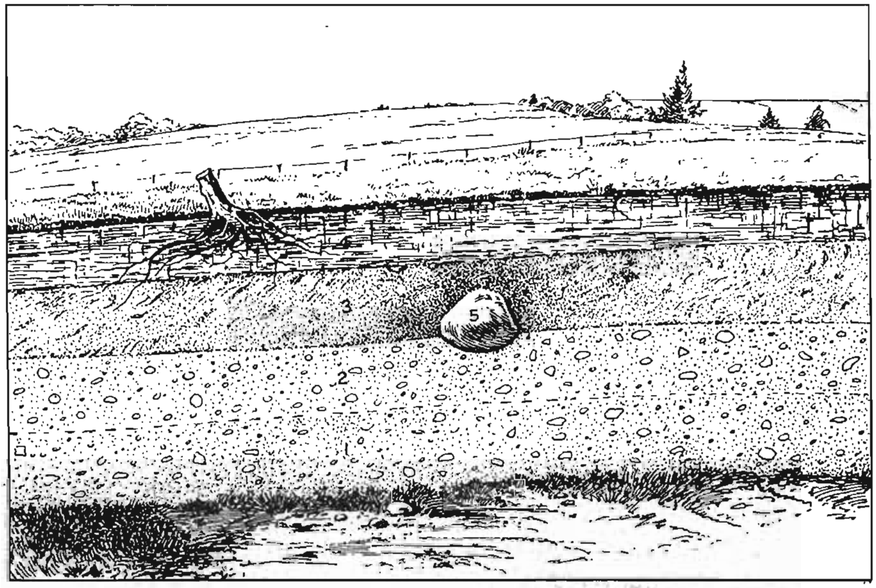


Fig. 13.—Diagram of drift exposed on electric railway near Bertram, Iowa, showing relations of till (1 and 2), wind-blown sand (3), and loess and soil (4), to an included etched and polished bowlder (5).

DRIFT NORTHWEST OF BERTRAM.

		Feet.
4.	Loess, buff-brown	3±
3.	Alternating buff sand and brown clayey sand stratified, with cross-beds dipping eastward, wind-blown	5
2.	Till, sticky, brown, pebbly, noncalcareous clay	3±
1.	Till, dense, dark slate-colored, highly calcareous	10+

Lying on the surface of the weathered till (No. 2) and embedded in No. 3 was a bowlder of coarse-grained red granite about three feet in diameter, whose sides and upper surface were etched and polished as by a sand blast. This sand was probably blown from the broad bottom of Cedar river about one mile to the southwest.

Conclusion as to the sources of the loess.—From the foregoing considerations it appears probable that the sources of supply of the loess in and adjacent to the Iowan drift area were in some cases the valley flats, in others the Iowan drift plain. The writers do not, however, extend this interpretation to the loess of southern and western Iowa and adjacent parts of Missouri, Kansas, and Nebraska, not wishing to express in this connection an opinion as to the sources of the loess of these more distant areas.

STRATIGRAPHIC RELATIONS OF THE LOESS.

Relations to the Kansan drift.—In the Kansan area the loess mantles the slopes as well as the uplands, showing clearly that the Kansan drift-plain was dissected before the loess was deposited. There are also numerous sections which show this unconformity in another way; calcareous and fossiliferous loess overlies highly weathered Kansan drift. This is well shown by the relations in the cut near the west end of the interurban railway bridge west of Iowa City. Here approximately thirty feet of buff loess, leached of calcium carbonate to a depth of about ten feet, and calcareous and fossiliferous below, rests on nine feet of thoroughly leached, highly oxidized and partly decomposed Buchanan gravel, which lies in a sag on reddish leached Kansan till. The buff loess at its base grades into somewhat coarser, noncalcareous reddish material which may have been swept from the red soils of adjacent surfaces of Buchanan gravel or Kansan drift.

Widespread over the Kansan drift area south and east of the Iowan drift plain, a red soil or ferretto is found underlying the loess where these are exposed in many railroad and highway cuts. In the new Chicago, Milwaukee & St. Paul railway cuts near Melbourne in Marshall county, near Vining in Tama county, and east of Delmar Junction in Clinton county, the loess overlies the ferretto and the eroded surface of the Kansan drift.

Calcareous loess overlying noncalcareous super-Kansan "gumbo" has already been cited (See also Plate XI). The story told by this relation is the same as that read from the foregoing relations. In fact the evidence throughout the loess-covered Kansan drift area, from Marshall and Jasper counties on the west to Mississippi river on the east, and from Clinton county on the south to the Minnesota line on the north, shows that a long period of weathering and erosion intervened between the deposition of the Kansan till and that of the loess under consideration.

Relations to the Illinoian drift.—The loess is continuous across the Kansan drift to the Illinoian area in southeastern

Iowa, and mantles the Illinoian drift. An examination of the deposit at many points in Scott, Muscatine, Louisa and Des Moines counties shows it to have practically the same constitution and amount of modification by weathering as the loess farther north.

Cuts on the Davenport and Muscatine interurban railroad through upland divides four miles west of Davenport, expose twelve to twenty feet of buff loess, leached to depths of seven or eight feet, and calcareous and fossiliferous below. There is a mantle of loess even on the flat upland which generally is thicker than the eight-foot auger could penetrate. In most places it is leached at least eight feet, but in one or two instances calcareous loess was struck at six to seven feet. In a few other places northeast and northwest of Davenport, the thickness of noncalcareous loess noted ranged from five to eighteen feet. In the area west of Muscatine, buff loess, with a leached zone similar to that of the loess immediately bordering the Iowan drift area, mantles the Illinoian drift to depths of more than eight feet. The same is true about Wapello, and also west and north of Burlington, excepting that in the latter locality the loess is slightly thinner. Here no thicknesses greater than five to seven feet were noted, and in most cases it is leached throughout its entire thickness.

Examinations of the loess by Mr. Alden in the Illinoian drift area, in parts of Rock Island, Henry, McDonough, and Fulton counties, Illinois, showed the prevalence of similar characteristics as to thickness, composition, fossil content, and amount of modification by weathering. This deposit is continuous eastward to and across Illinois river where, as shown by Mr. Leverett,[52] it passes under the early Wisconsin drift in the region of Peoria.[53]

While the loess lying on the Illinioan till is apparently of the same age as that overlapping the Iowan drift, it seems clear that the Illinoian till suffered much more modification by weathering and erosion prior to the deposition of the loess than did the Iowan drift. This is discussed in the following chapter.

[52]Illinois glacial lobe, U. S. Geol. Survey Mono. 38, p. 187, 1899.

[53]In places along the Mississippi bluffs there was observed light gray to light buff loess which is leached to a depth of but two to four feet. This may be the product of later eolian deposition, continuing to the present.

Relations to the Iowan drift.—In the area of the Iowan drift the loess is generally so thin that the leached zone extends down into the till. None of the exposures or borings revealed calcareous loess overlying leached till. On the other hand, at least one section, in an interurban railroad cut near Lisbon, Linn county, exposed calcareous till immediately beneath calcareous loess and sand. The relations noted at this place were as follows:

DRIFT WEST OF LISBON, IOWA.

	Feet.
Loess, leached	6
Loess, calcareous	2-3
Sand	1-2
Till, calcareous	2-3

Relations similar to these were found by making borings in the southwestern part of the Iowan drift area, in Benton, Tama, and Grundy counties. The loess in this latter territory is thicker than in the rest of the Iowan area, and lies as a general mantle with an average thickness of four to six feet. In penetrating this again and again with the auger, it was found that the loess was wholly leached but that the till beneath was rarely leached more than a few inches to one and one-half feet. In other words, where the covering of loess on the Iowan drift is thicker the leaching of the till is less. This strongly suggests that the leaching process has but recently reached the till. The absence of any deeper color due to oxidation of the upper part of the till as compared with the color of the overlying loess is of like significance. It indicates that the Iowan till suffered but little modification by weathering before the loess was deposited upon it. There is generally at the top of the till and beneath the loess, as seen in cuts, a more or less definite line of pebbles. This is probably the residual coarse material left from the slight wind erosion and rain wash which occurred at those particular places before the till was protected by the loess.

In line with the foregoing evidences is the fact that no soil was seen between the loess and the underlying till in the area of the Iowan drift such as was observed in the Illinoian drift area in the vicinity of Wapello and Burlington. Moreover, the Iowan till, where not loess-covered, is leached to somewhat less depths than the average sections of loess in the bordering Kansan drift area. This is in harmony with the textures of the two formations. Since the loess is more porous than the till, it should show a greater depth of leaching if both are of approximately the same age.

All these considerations of the character and relations of the loess lead to the conclusion (1) that a very long time intervened between the disappearance of the Kansan ice sheet and the deposition of the main sheet of loess under discussion, (2) that there was also a considerable interval after the Illinoian ice melted away before the Illinoian drift became mantled with loess, and (3) that on the contrary, the deposition of this loess followed almost immediately the recession of the front of the glacier which laid down the Iowan drift.

This conclusion may at first seem incompatible with the presence of the fossil shells which, according to Professor Shimek, are like those species of snails which live in the same region today and feed upon vegetation. It should be recognized, however, that the climate at the close of a glacial epoch is probably different from that at the beginning. The formation and extension of a glacier is a consequence of glacial conditions having prevailed for some time. Its development and advance are preceded first by a change to glacial temperatures and a vast accumulation of snow. The retreat of the ice front, on the other hand, occurs only when the interglacial climate has become well established. Probably a zone adjacent to the retreating front of a continental ice sheet is affected by cold winds blowing from its surface and somewhat by the presence of the ice itself, but the conditions are less severe than in the case of an advancing ice sheet. In the former case, the climate opposes the existence of the ice, while in the latter, it is responsible for it. Although present temperatures probably did not prevail in the immediate vicinity of the Iowan ice, it seems likely that after the climate had so changed that the ice had melted back hundreds of miles from its extreme limit, seasons approximating those of the present may have prevailed over those areas where the loess now occurs. The length of time consumed in a retreat of even a thousand miles would be brief geologically, and probably would not have resulted in any conslerable amount of weathering of the new drift. The statement, therefore, seems sound, that the main sheet of loess under consideration was deposited immediately following the Iowan stage of glaciation. It is therefore a near-correlative of the Iowan drift, though it really represents the early part of the Peorian stage of deglaciation.

Relations to the Wisconsin drift.—If the conclusion is sound that most of the loess in and adjacent to the Iowan area was deposited immediately following the Iowan stage of glaciation, the main deposit of loess should be found extending beneath the Wisconsin drift.

No sections were observed by the writers in Worth, Cerro Gordo or Franklin counties showing either the Iowan drift or the overlying loess extending westward under the late Wisconsin drift of the Des Moines lobe. Neither have such exposures been reported by the Iowa Geological Survey. No thorough search for such was made by the present writers nor was there any extended examination of the Wisconsin drift. A few short trips were made across the border in the last three of the counties named. In most of the places seen there was no loess on the Wisconsin drift. In a few places in Franklin a thin coating of loess or loesslike loam was found on the marginal slope of the Wisconsin drift while thicknesses of one to ten feet were found quite generally on the Iowan drift to the east. At one point six miles southwest of Ackley, Hardin county (near middle of south one-half of Aetna township, Township 89 North, Range 19 West), in the area of the Wisconsin drift, a boring was made which penetrated leached loess four and one-half feet and calcareous loess three and one-half feet without reaching the underlying till. This is probably a rather exceptional deposit blown up from Iowa river about one mile distant. On the Iowan drift plain to the east thicknesses of one to eight feet were observed, the lower part being calcareous where the thickness was greater than four to four and one-half feet.

These are, of course, not the first observations of slight local deposits of loess overlying Wisconsin drift.[54] Similar occur-

[54] Salisbury, R. D., Loess in the Wisconsin drift formation. Jour. Geology, Vol. 4, pp. 929-938, 1896.

View of drift exposed in Chicago, Milwaukee & St. Paul railway cut southwest of Rhodes, Iowa, showing Kansan till (1); super-Kansan gumbo (2); loess (3); Wisconsin till (4).

rences have been noted by Mr. Leverett at various places in Illinois[55] and by Mr. Alden at various places in southern Wisconsin and in Bureau County, Illinois.

Shimek has described post-Wisconsin loess also and has shown that some loess deposition has continued to the present time and is yet going on. These deposits of known Wisconsin or post-Wisconsin age should not, however, lead to confusion of the discussion in hand, which is that the loess formerly called "Iowan" but deposited during the Peorian stage of deglaciation, extends beneath the Wisconsin drift.

In southeastern Hardin county and in Marshall county the Iowan drift does not extend westward to the Wisconsin drift boundary but the loess is continuous across the interval and passes beneath the later drift. In his report on the geology of Hardin county[56] Prof. S. W. Beyer wrote as follows:

Outcrops of the loess may be observed well across Providence township, and the loess undoubtedly continues under the Wisconsin drift and connects with the deposits near Ames in Story county. On the southeast quarter of section 6 in Providence township the loess appears in a cut along the roadway overlain by twenty feet of Wisconsin drift and resting upon the oxidized Kansan. Also in section 16, in a road cut, eight feet of loess is visible. The deposits at these exposures are closely set with root casts, some of which measure four inches in diameter. Loess concretions are numerous and a few gasteropod shells were noted, the most common being a species of Succinea.

At a point about twenty-seven miles south of the Hardin county exposure, the writers found similar relations exhibited by a cut on the Chicago, Milwaukee & St. Paul railway in the northwest quarter of section 19, Eden township (Township 82 North, Range 20 West), Marshall county. At this place, which is about three miles southwest of Rhodes, the railway climbs from the dissected area of the Kansan drift to the Wisconsin drift plain. The big cut at the county line (Plate XI) showed the following section:

[55]Leverett, F., The Illinois glacial lobe, U. S. Geol. Survey Mon. 38, pp. 267-268, 1899.
[56]Beyer, S. W., Geology of Hardin County: Iowa Geol. Survey, Vol. X, p. 282, 1899.

DRIFT IN CHICAGO, MILWAUKEE & ST. PAUL RAILWAY CUT THREE MILES SOUTHWEST OF RHODES, IOWA.

		Feet.
4.	Till, Wisconsin, leached three feet, calcareous below......	25
3.	Loess, mostly buff, gray at bottom, leached four or five feet in one place, snail shells in calcareous portion........	25
2.	"Gumbo," noncalcareous gray clay, similar to that found elsewhere on the Kansan drift, contains small pebbles....	8-10
1.	Till, probably Kansan, brownish buff, contains rotten granites, leached 9-10 feet, calcareous below; exposed.....	5-12

An irregular ferruginous line or shell two to three inches thick extends obliquely through part of the loess and ends at the base of the Wisconsin till as though cut off.

Here it is clear that the loess was deposited not only before the late Wisconsin ice invasion, but at a time separated therefrom by an interval of leaching and oxidation (the Peorian interglacial stage of Leverett).

As noted above (page 155) Mr. Leverett has shown that the loess also extends eastward beneath the early Wisconsin drift in the region of Peoria, Illinois.

SUMMARY OF THE RELATIONS OF THE LOESS.

1. The loess in and about the Iowan drift area is believed to be mostly wind-blown material.

2. The sources of supply were in some cases the surface of the Iowan drift, in others the valley flats both within and outside of the Iowan area.

3. It is probable that this loess was, for the most part, originally calcareous.

4. If it was originally calcareous, that part which was blown from the surface of the Iowan drift must have been derived before the drift was leached. This is one reason for regarding its age as immediately post-Iowan or, in other words, early Peorian. This is in agreement with the evidence showing that the Iowan drift was but little eroded or modified by weathering prior to the deposition of the loess.

5. The Kansan drift area was probably already clothed with vegetation when the accumulation of this loess began, as is indicated by the presence of herbivorous land-snails in the loess. The change from a glacial to an interglacial climate, which had already initiated the retreat of the Iowan ice front made such

vegetation possible. This vegetation, especially the arboreal, was a factor in affording lodgment for the loess, as was also the rough topography of the Kansan.

6. The recently exposed surface of the Iowan drift undoubtedly had some vegetation soon after the melting of the ice, but it was probably sparse. There is nothing to show that arboreal vegetation ever gained much of a foothold in the Iowan drift area excepting in the rougher parts and in narrow belts along the streams.

7. The broad prairies, when they were dry and where they were not effectively protected by prairie grasses, were undoubtedly sources for clouds of dust and sand, just as the ploughed fields of man and his unpaved highways have been since his appearance.

8. The till nuclei of the paha rising above the surrounding plain were well drained and favored the growth of arboreal vegetation and thus afforded increased lodgment for eolian materials.

9. In order that the loess could have accumulated as a calcareous deposit, the rate of deposition must have exceeded the rate at which the calcium carbonate was removed by leaching. It is therefore perhaps not incorrect to say that there was a special time of deposition for the loess which borders and overlaps the Iowan drift. This is particularly so since there was time for considerable leaching and oxidation of that part of this loess which now underlies Wisconsin till before that later till was deposited.

10. The time of main loess deposition probably did not end abruptly, but as vegetation more completely covered the drift, the amount of material blown about by the winds gradually diminished.

11. Although the time of main loess deposition is thought to have been short, geologically speaking, it is probable that the rate of accumulation of the loess even during that time was sufficiently slow for successive generations of plants to decay before the vegetable matter was buried to such depths as to be preserved.

CONCLUSIONS FROM THE RELATIONS OF THE LOESS.

The general conclusions from this study of the loess are those stated above (page 157); (1) that the deposition of the uppermost till of the Iowan drift area occurred but a short time prior to the accumulation of the main sheet of loess which borders and overlaps it; (2) that the Illinoian till was deposited at a time considerably before this epoch of loess deposition, and (3) that the Kansan drift was deposited considerably earlier than the Illinoian till and much earlier than the loess was formed, or in other words, this line of evidence also supports the view that the Iowan stage of glaciation was distinct from, and later than, either the Kansan or Illinoian stages of glaciation.

CHAPTER VIII

THE AGE OF THE IOWAN DRIFT.

Considerable evidence has already been presented tending to show that the Iowan drift is distinct from and younger than the Kansan drift. The amount of modification of the drift by weathering and the stratigraphic relations of the main deposit of loess show clearly that the Iowan drift is also distinct from and older than the Wisconsin drift. The Iowan drift is not now known to extend into the area covered by the Illinoian ice sheet nor to overlap the Illinoian drift, so that their mutual age relations can not be determined directly but must be inferred from comparison of the relative amounts of their modification by weathering and erosion and by their relations to the main deposit of loess. Reference has been made to these relations in the preceding chapters and the characteristics of the Iowan drift have been discussed at length. The Illinoian drift has been treated by Mr. Leverett in his monograph.[57] Some further consideration may be given to it in this connection.

In southeastern Iowa and in that part of western Illinois south of Rock river which was examined by Mr. Alden, the Illinoian drift area has a fairly uniform type of topography. The striking features are the broad upland areas (in many places

[57] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, 1899.

View of eroded Illinoian drift plain in Rock Island County, Illinois.

four to five miles wide) and the sharply incised valleys (Plate XII). The uplands are nearly flat, and comprise relatively much more area than do the remnants of the Kansan upland in Iowa (Plate I). The larger valleys average 100 to 150 feet in depth, and have valley flats one-half to one mile, or rarely two miles wide. Branching tributaries have partly dissected the bordering uplands, but on the whole they are short (Plate XIII). The broad, flat upland tracts with the sharply-cut valleys intervening, give the impression that the Illinoian ice on melting left a nearly flat drift plain. Since then sufficient dissection has taken place to develop drainage systems to a stage of late youth.

As compared with the Iowan drift topography (Plate II) the Illinoian shows considerably more erosion. In some parts of the Illinoian drift area this may be due partly to proximity to Mississippi river, which has resulted in fairly high gradients.[58] But on the other hand, the original surface of the Illinoian drift probably was nearly flat, whereas the surface of the Iowan drift originally had gentle slopes, with inherited major drainage lines. The latter condition is thought to be as favorable to the development of a drainage system as the former, if not more so; and, hence, the greater amount of erosion of the Illinoian drift appears to indicate a longer time of exposure.[59]

The weathering of the upper part of the Illinoian till was due to its exposure prior to the deposition of the loess. The oxidized zone is not generally cut off by the erosional slopes as is the ferretto at the top of the Kansan but it extends well down below the upland where the slopes are not too steep. The loess also mantles the slopes at least part way down where these are steep, and entirely to the bottom where they are not so steep. Most of the erosion and oxidation of the Illinoian till thus appears to have been accomplished prior to the deposition of the loess.

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[58]See Milan and Edgington topographic maps.

[59]In this connection it may be noted also as a somewhat anomalous condition that for a distance of 80 to 100 miles southwestward from northern Knox county, Illinois, and the region of Galesburg, the watershed between Mississippi and Illinois rivers is much closer the major than the minor stream. In northern Hancock county the divide is in places but five or six miles from the Mississippi, while the drainage on the east flows fifty miles or more to Illinois river. The topography of this part of the Illinoian area is well illustrated by the Colchester, Macomb, Avon, and Canton topographic maps. Certainly this part of the Illinoian drift area has not had much advantage over the Iowan drift area on the basis of contiguity to Mississippi river, however Illinois river may have affected it.

There seems to have been comparatively little erosion since the loess was laid down.

Near Davenport, Iowa, in the cuts above referred to, the loess lies on slopes of erosion of the Illinoian and older tills, and the calcareous and fossiliferous portion of the loess rests on till oxidized to a brownish tint and leached to depths of about six feet. In the vicinity of Wapello, Iowa, there are exposures showing a buried soil separating the loess from till, and in some places a "gumbo"-like clay is found at this horizon. In Grandview township (Township 75 North, Range 3 West) south line of the southeast quarter of section 33, there was exposed in both sides of a ravine the following:

DEPOSITS FOUR AND ONE-HALF MILES NORTH OF WAPELLO, IOWA.

		Feet.
2.	Loess, buff, rusty at bottom	12
1.	Silt, almost black like soil at top, dark drab below, "gumbo"-like in texture, with scattered small pebbles and sand grains, noncalcareous	5- 6

In Port Louisa township (Township 74 North, Range 3 West), north-central part of section 10, a road cut on a valley slope showed:

DEPOSITS THREE AND ONE-HALF MILES NORTH OF WAPELLO, IOWA.

		Feet.
2.	Loess, buff, rusty at bottom	10
1.	Soil (contact sharp), exposed	1

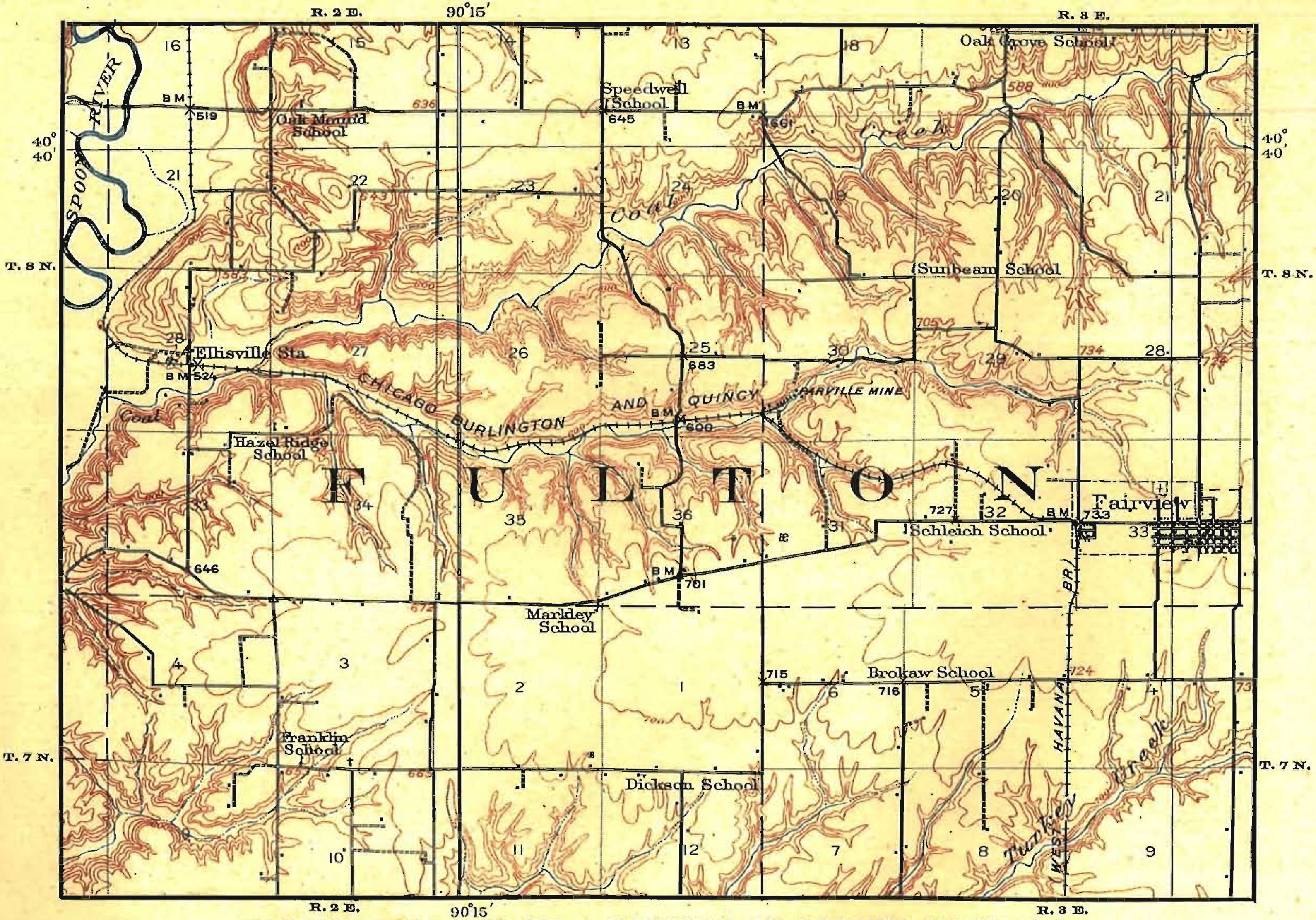
At neither of these places was the underlying till exposed.

Some of the more deeply weathered till exposed in these counties, especially in cuts well below the upland level, may be Kansan. At these places the Illinoian till is absent beneath the loess, apparently as the result of preloess erosion, and if the weathered zone is absent, it is not always possible without careful examination to determine whether the till exposed is Kansan or Illinoian. Where moderately weathered till is exposed at the higher levels the presumption is that it is Illinoian. Professor Udden found a lithologic difference between the Kansan and Illinoian till of this region but the writers made no such careful comparison.

In 1905, Mr. Alden examined an exposure in Wapello township, (Township 74 North, Range 3 West, northwest quarter of

FROM U. S. G. S. TOPOGRAPHIC MAPS
(AVON AND CANTON SHEETS, ILLINOIS)

IOWA GEOLOGICAL SURVEY
PLATE XIII



TOPOGRAPHIC MAP OF A PORTION OF ERODED ILLINOIAN DRIFT PLAIN IN FULTON COUNTY, ILLINOIS

Scale $\frac{1}{62,500}$

1 ½ 0 1 2 3 Miles

Contour interval 20 feet.

Datum is mean sea level.

section 15), in the face of the bluff east of the north end of the Iowa river bridge. When seen in 1914 the section was badly obscured by slumping but peat and soil could still be seen beneath twenty-five feet of loess and sand. The section when seen in 1905 showed the following deposits:

SECTION OF IOWA RIVER BLUFF TWO AND ONE-HALF MILES NORTH OF WAPELLO, IOWA.

		Feet.	In.
11.	Sand, stratified	10-15	
10.	Loess, buff to gray	10	
9.	Loess and sand, interstratified	5- 6	
8.	Humus, dark	1- 1½	
7.	Peat containing fragments of trees	2	8
6.	Humus, black to grayish	4	
5.	Sand, yellowish gray, obscured	?	
4.	Clay (till?), leached, jointed, mottled reddish gray to bluish gray, speckled in upper part with light spots and bright blue spots	11-12	
3.	Clay, rusty, oxidized		0- 3
2.	Clay, ashen gray		8-12
1.	Sand, fine, stratified	10	
	Talus.		

Udden describes the Sangamon soil, which separates the Illinoian till from the overlying loess, as well developed at many places in Louisa county. The peaty phase is said to be most pronounced in the east bluffs along Iowa river northeast of Wapello.

North of Burlington, soil and gray "gumbo" were seen beneath the loess in Burlington township (Township 70 North, Range 2 West), west line of section 4; in Franklin township (Township 71 North, Range 3 West), southeast quarter of section 13; and in Yellow Springs township (Township 72 North, Range 3 West), central part of section 32. Borings made by the writers on the flat upland near the south line of section 2, Franklin township, and in Flint River township (Township 70 North, Range 3 West) at the middle of the north line of section 2, revealed a black soil beneath about seven feet of loess. In the former place the lower three and one-half feet of the loess was gray and calcareous. In this county, as in the others, the loess mantles the slopes as well as the uplands.

Doctor Kay[60] states that "after a somewhat careful study of the gumbo which lies on the Illinoian drift in southeastern Iowa,

[60]Kay, Geo. F., Gumbotil, a new term in Pleistocene geology: Science, new ser., Vol. XLIV, pp. 637-638, 1916.

and which was discussed by Leverett in Monograph XXXVIII of the United States Geological Survey, pages 28 to 33, the conclusion has been reached that here, also, the gumbo is so related to the drift that it is undoubtedly the thoroughly weathered product of the Illinoian drift."

Mr. Leverett has discussed the Sangamon soil and weathered zone as developed in Illinois.[61] He describes one extensive exposure of the soil as found at the Brick and Tile Works in Galva (Henry county). Here fifteen feet of loess is underlain by one foot of black mucky soil in which was embedded a log one foot in diameter. Beneath this was the Illinoian till.

Mr. Alden also observed the loess in similar relations to the weathered and eroded drift in that part of Illinois lying south of the big bend of Mississippi river and the Green river basin, although only slight traces of black soil were noted by him at the Sangamon horizon.

From these various observations it is evident that the Illinoian drift has been modified much more by weathering and erosion than has the Iowan. It also appears that most of the modification of the Illinoian occurred prior to the formation of the main deposit of loess. It seems clear therefore that the Iowan drift is entirely distinct from and considerably younger than the Illinoian drift. At the Illinoian stage of glaciation the Labrador ice sheet extended to and across Mississippi river in southeastern Iowa. The relations of the Keewatin glacier at that time are not known. During the Sangamon stage of deglaciation the Illinoian drift was considerably eroded, its upper part was leached and oxidized, soil and vegetable deposits were formed and, in places, a super-Illinoian "gumbo" was developed. This was followed by the extension of an ice sheet from the Hudson Bay region southward into northeastern Iowa and the deposition of the Iowan drift. The relations of the Labrador glacier at this stage are not now known. Accompanying and following the melting of the Iowan ice prevailing conditions resulted in the accumulation of the main deposit of loess. This represents the early part of the Peorian stage of deglaciation. During the later part of this stage the Peorian soil and weath-

[61]Leverett, F., The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 125-130. 1899.

ered zone was developed and the loess and Iowan till were subjected to some erosion, leaching and oxidation. This stage of deglaciation was followed by an extension of the ice from both the Labrador and Keewatin centers, that from the latter overriding the Iowan drift excepting in northeastern Iowa and, perhaps, in southeastern Minnesota and some areas farther west. At one of the oscillations of the Keewatin ice sheet of the Wisconsin stage the Des Moines lobe occupied north-central Iowa. On its melting the Recent epoch was inaugurated. The consideration of the various lines of evidence reviewed in this paper leads the writers to the conclusion stated in the Introduction, that there is warrant for the continued use of Iowan drift and Iowan stage of glaciation as major subdivisions of the Pleistocene classification.

CHAPTER IX

BORDER PHENOMENA AND LIMITS OF THE IOWAN DRIFT.

It seems necessary to make some statement concerning the definition of the limits of the Iowan drift. It should be understood, however, that but little work was done by the present writers on either the determination of the exact limits of this drift sheet or on the verification or revision of the boundaries as previously mapped. The time devoted to the field work was spent, for the most part, in the study of the broader questions involved. Owing to the similarity in lithologic composition of the Iowan and the Kansan drifts, as noted above and as shown by the tabulated results of pebble counts (Tables, Appendix A) and the paucity of terminal morainal phenomena, it would probably be difficult if not impossible to determine accurately in detail the present limits of the Iowan drift. In a general way the border can probably be approximately located as at or near the places where the undissected and mantled topography of the Iowan area gives way to the dissected topography characteristic of the older drift. The drift is probably generally thin and doubtless it has been removed by erosion from the more dissected tracts bordering the main streams. It seems to the writers that the line shown on the published maps is rather the inner limit of the thicker parts of the loess than the actual outer boundary of the Iowan drift, either as at present preserved or as originally deposited. While there is not a great deal of loess in the Iowan area, the Iowan drift and the loess are probably not in reality so nearly mutually exclusive as was originally supposed. As indicated above (Chapter VII), there is in many places a certain amount of loess overlying the Iowan drift. On the other hand there are some neighboring areas showing little or no loess which the Iowan ice may not have covered.

A portion of the northeastern border of the Iowan drift is fairly well defined, and at intervals along this border there is a mild development of morainal phenomena. Five miles southwest of Ridgeway (Sumner township, Township 97 North, Range 10 West) a tract was observed showing morainal knolls. When the tops of two of these were dug into, gravels were exposed. About a mile west of Fort Atkinson (Washington township, Township 96 North, Range 9 West, section 7) knolls of drift sprinkled with bowlders and pebbles mark the border of the Iowan. They appear to be banked at the head of a tributary of Turkey river. With these is a limestone hill forty feet high.

Three miles east of Ridgeway, on K. P. Kuntson's farm, in Winneshiek county, in section 20 of Madison township, there is a moraine, trending a little north of west. The line of hillocks rises as much as forty feet above the nearly flat, upland plain to the south. The area to the north is deeply dissected. A gravel pit fifteen feet deep in one of the hillocks shows it to be a kame. The material is rather coarse, partly water-worn gravel which ranges from sand to cobbles six to eight inches in diameter, though it averages one-half inch to one and one-half inches. It is cross-bedded, with a dip as high as 30 degrees. An estimate of the percentages of the various kinds of rock-types made by counting and sorting pebbles shows the following:

	Per Cent		Per Cent
Limestone	32	Quartz	2
Granite	15	Chert	2
Greenstone	26	Sandstone	2
Quartzite	15	Porphyry	1
Dolerite	4	Ironstone	1
		Total	100

Some of the limestone pebbles, as well as some of the others, have a slight rusty and black coating. Incipient cementation is present, but so little that with the stroke of the hammer the gravel falls freely. As a result of leaching the upper five feet are barren of limestone pebbles.

Some low moraine-like knolls appear to mark the Iowan border near Conover. A cut and boring show the presence of till. The nearby kettle-like depression may really be a limestone sink and not a glacial kettle-hole.

In the northeastern part of Howard county there is a belt of swells, but so far as they were seen the knolls appeared to be of loess and not morainal. The same is true in southeastern Orleans township, Winneshiek county.

Two to three miles south of Conover, the head of a tributary of Youngs creek appears to be blocked with drift. A well here shows the presence of forty feet of drift, though drift is very thin to the eastward. It is probable that the Iowan ice extended somewhat east of this drift ridge down the broad open swales that lead to the upper terrace or second plain which is so well developed in this region. The outwash gravels extend into and through the inner gorge, which is here cut eighty feet or more below this upper terrace level.

In the northern part of Windsor township, Fayette county (Township 94 North, Range 9 West), five or six miles northwest of West Union, a moraine-like ridge lies along the border of the Iowan area as mapped. Some small sags occur with the knolls. A cut and boring in one of the swells showed seven feet of leached till over calcareous till; another cut exposed only loess.

Two to three miles southeast of West Union (Union township, Township 94 North, Range 8 West, sections 27 and 28, and also in section 32) there are ridges and knolls at the Iowan border.

It is possible that some of these are of loess but others are certainly of drift.

Along the Iowan border between Fayette and Arlington are numerous low knolls. Some of these are of gravel, others are of loess or loess-mantled drift. It is in this belt not more than two or three miles southeast of Fayette that excavation for the railway cuts exposed the two tills with intercalated forest bed which are cited by McGee.[62]

The main road from Strawberry Point to Edgewood in southwest Clayton county follows a well-defined ridge which marks the border of the Iowan area. Cuts expose ten to fifteen feet of loess, but most of the bulk of the ridge is probably of till. Records of several wells show thicknesses of 100 to 200 feet of clay above the limestone.

Some knolls occur southeast of Edgewood. In section 8 Bremen township (Township 89 North, Range 3 West) a ridge of gravel knolls rises sharply in true morainal fashion thirty to forty feet above the surrounding land. The gravels are, however, oxidized brownish and considerably decomposed (about as much as the Buchanan gravel). Gravels which are exposed two to three miles farther west, in Oneida township (Township 89 North, Range 4 West, section 12, west line), are less deeply weathered.

There may be some question as to whether or not the Iowan ice really extended farther southeast and south of this point in the area east of Maquoketa river and south of the Illinois Central railroad in the southeast part of Delaware county. While the topography of the narrow upland plain between Dyersville and Farley closely resembles in part that of the typical Iowan plain, the relations of the drainage between Dyersville and Farley are somewhat anomalous, and the amount of weathering of the drift exposed and of that penetrated in several borings is greater than that commonly noted on the Iowan. The writers have therefore some doubt as to the Iowan ice having extended beyond Dyersville. East of Farley the erosion lines sharpen immediately north and south of the narrow upland strip. No calcareous material was found in the drift here

[62]U. S. Geol. Survey Eleventh Ann. Rept., pt. 1, p. 487-489.

within eight to fourteen feet of the surface. Although in numerous places, the limestone outcrops or is but thinly covered, there is some thick drift. A well on the Onstreide farm (New Wine township, Township 89 North, Range 2 West, section 35, southeast quarter), about two miles northwest of Farley, is reported to have penetrated 115 feet of drift. Apparently there is here a buried valley as the present drainage lines are cut into limestone not far away. The shifting of drainage here may account for the lack of dissection.

While the writers have not examined the area of the supposed Worthington-Barnard lobe except for parts near Worthington, it appears from study of the published description, the topographic maps, and field notes of Mr. Leverett and Professor Chamberlin, that there is little real basis for mapping this as having been occupied by a lobe of the Iowan ice. The distribution of the bowlders and of the loess does not seem to the writers to define the limits of the Iowan, while the topographic relations render such a lobate extension inherently improbable. Doctor Calvin and some of the other observers appear to have reached the same conclusion. While there are considerable tracts of smooth, nearly flat, topography resembling the topography of the Iowan area south of the Illinois Central railway, other parts, as southeast of Delhi, are greatly dissected. Rough weathered limestone is exposed (often in projecting ledges) at numerous places and the till where seen is considerably weathered. In some places it is not, however, more weathered than the known Iowan. One hill, in this area, the sharp forty-foot ridge two miles north of Sand Spring (South Fork township, Township 87 North, Range 3 West, sections 9 and 10), is quite clearly built of Kansan drift, as the road in the crest exposes, beneath seven feet of loess, the well-marked red ferretto of the top of the Kansan till.

Two or three miles northeast of Sand Spring is a moraine-like belt of hills. The gravels exposed in a pit in one of these hills (South Fork township, Township 87 North, Range 3 West, section 11, southwest quarter) are much weathered. Limestone pebbles are mostly absent from the upper part of the fifteen-foot section as they have been removed by solution excepting some deeply etched blocks on the surface. Limestone pebbles are present lower down but some are so badly decomposed as to crumble to powder in the fingers. Granites crumble under the hammer; greenstones have rusted exteriors; clay ironstones have formed, and pebbles are much coated with iron oxide, manganese dioxide or calcium carbonate. If the Iowan ice really did extend into this area these gravels may perhaps be regarded as part of its terminal moraine. They may, however, be older.

If the Iowan ice extended onto the upland west of Cascade, it is difficult to see how it could have avoided occupying the valley of Maquoketa river, yet the constricted winding gorge below Monticello with vertical cliffs and castellated towers of limestone shows the characteristics of the Driftless Area rather than a valley so recently glaciated. It seems probable that the ice did not extend farther down than the head of this gorge near Monticello. The writers have also some doubt as to all of the gently undulating strip of country which extends from Monticello and Langworthy southeast to Onslow, having been glaciated at this time. The drift in this tract varies from one foot or less to 260 feet or more, as shown by the records of wells.[63] Its undissected topography is apparently due to the results of stream shifting by the Kansan ice sheet. While the Maquoketa was forced to entrench itself in the rock but a short distance to the north, the surface configuration of this belt caused half of this area to drain in a reverse direction to the main stream at Monticello and this course has led the little brook across outcropping rock ledges. Both factors have retarded dissection; the eastern part drains east to the main stream but this has also been retarded by cutting in limestone. The pre-Kansan or preglacial drainage was probably southward to Wapsipinicon river, but a big drift ridge now lies athwart this course. It seems to the writers probable that the margin of the Iowan ice lay across the plain somewhere east of Langworthy, but that it did not extend so far east as Onslow.

The drift ridge indicated extends northwest from Wyoming past Amber toward Prairieburg. As shown on page 93 there

[63]U. S. Geol. Survey Water-Supply Paper, No. 293, p. 437-441, 1912. Iowa Geol. Survey, Vol. XXI, pp. 528-532, 1912.

is good evidence that the Iowan ice overrode this ridge southeastward to a point about a mile beyond the line of the Chicago, Milwaukee & St. Paul Railway. This is shown by the smoothed-out contours of the ridge farther northwest and by the presence on top of the ridge south of Langworthy of thin Iowan drift overlying the super-Kansan soil and "gumbo." Farther southeast the ridge is much dissected, the glacial till is deeply weathered, and such traces of the "gumbo" as have been found have no overlying later drift. It therefore seems probable that the margin of the Iowan ice lay across this ridge not far east of the line of the Chicago, Milwaukee & St. Paul Railway. South of this it must have occupied the valley of Wapsipinicon river, though the valley slopes show little or no evidence of its presence.

From the latitude of Anamosa southward to Iowa river in Johnson county there is such an alternation of smoothly undulating plains and loess covered hilly tracts together with the dissected belts bordering the Wapsipinicon, Cedar and Iowa rivers, that there is considerable ground for difference of opinion as to just what areas were covered by the Iowan ice. It is, indeed, doubtful whether any two observers working wholly independently would reach similar conclusions. The presence of rather low, gently undulating, undissected tracts of considerable size, with here and there a big granite bowlder and even with till but moderately weathered leads, on the one hand, to the mapping of a long lobe extending fifty or sixty miles southeastward from the main Iowan area to the Mississippi near Clinton. On the other hand, the inherent improbability of the extension of a lobe of any such length and with so small a width (only eight or ten miles in southern Jones and northern Cedar counties), makes one hesitate to consent to any such mapping especially when the relative elevations of this and adjacent tracts are considered.

There is little or no evidence as to the relations of the ice front to the Wapsipinicon valley above and below Anamosa. The slopes are sharply dissected and loess-mantled. At the few places where till was seen by the writers it showed considerable evidence of weathering, such as the red ferretto zone of the Kansan. Whatever Iowan drift was deposited on these slopes has probably been removed by subsequent erosion or covered by the loess.

It has been supposed that the margin of the Iowan ice extended from the vicinity of Olin in southern Jones county, southeastward along the south border of the loess-mantled hills which lie south of the Wapsipinicon between Olin and Massilon. These hills appear to be of Kansan drift mantled with eight to ten feet of loess. The belt south of the Wapsipinicon between the Chicago, Milwaukee & St. Paul and the Chicago & North Western railway lines, has in part a gently undulating topography of the Iowan mantled type, for example north of Stanwood and Clarence. In large part, however, it is occupied by hills which, so far as is known, are principally of Kansan drift with a moderately thick coating of loess. Those with the northwest-southeast trend, the paha of McGee, are particularly notable. The writers have little data in hand showing definitely the presence of Iowan drift in this area even as far east as the Wapsipinicon valley in western Clinton county. There is even more question as to the extension of the Iowan ice farther east. The inherent improbability of the extension of such a lobe increases with the distance. This part of the Wapsipinicon valley is evidently one of the oldest valleys in eastern Iowa. It is pre-Kansan if not preglacial in origin. The relatively low elevation of the land for a distance of six to eight miles north of the stream is probably due to early denudation. Tributary valleys filled by Kansan drift have not been reëxcavated so that though there is little irregularity of the surface the thickness of the drift ranges from a foot or less, at points where the limestone is exposed, to 220 feet or more as shown by wells. Much of this area lies below the level of submergence caused by the shifting of Mississippi river through the Goose Lake channel at the time of the Illinoian ice invasion (that is, 700 to 720 feet above the sea level). From this submergence may have resulted the deposition of much of the sand found throughout this area and as a consequence some of the smoothing of the contours. Sand deposited on the lower levels has also been blown about and has mantled some of the higher tracts. The relatively low relief, together with the relatively short time since the disappearance of the Illinoian ice and the drainage of the submerged areas, has not favored subsequent dissection. These conditions may also account for the very moderate amount of modification of the till noted at several places where test borings were made in the region east of De-Witt. There is, therefore, considerable ground for question as to the Iowan ice really having invaded Clinton county to any great extent, even if it reached as far east as Wheatland. It may be possible that the Iowan ice front curved in southwestern Jones county in the region of Morley and swung southwestward to Cedar river as far west as Lisbon in southeastern Linn county, so that there may have been no Clinton lobe of the Iowan sheet. This must, however, still be regarded as an open question.

The tract west of Tipton in Cedar county which shows some Iowan characteristics is small and so isolated in the midst of a region of erosional topography that the writers are loth to think that a lobe of the Iowan ice lay over it. It differs but little from an area of little dissected Kansan upland in the southeast part of the county in the vicinity of Sunbury, yet the relations of the loess and of several paha render it like some Iowan tracts. Most of the cuts seen between Cedar Bluff and Tipton show only loess or dune sand. A cut and boring on the nearly flat upland north of Buchanan showed the presence of what appeared to be the super-Kansan "gumbo" at the top of leached and oxidized till. One boring on this upland showed calcareous till immediately below thin loess. Considering everything, and especially the erosional character of the topography surrounding this small area it seems doubtful if the Iowan ice ever occupied the tract in question.

Concerning that part of the tract north of Cedar Bluff (and the same is true of the whole belt northwest to the vicinity of Mount Vernon), Professor Norton wrote:[64]

* * * In this limited area the aspect of the topography is abnormal in the depth of the rock-cut valleys, the width of flood plains, and the amount of dissection. The bowlders scattered over the surface and the fact that it lies in the direct and only path to the typical Iowan area west of Tipton, are, perhaps, sufficient reasons for mapping this region of western Linn township as Iowan, although the ice here passed over without

[64]Iowa Geol. Survey, Vol. XI, p. 372

altering to any marked degree the lie of the land. Here no clear marginal ridge marks the separation from the Kansan to the north and it is hard to draw the line of demarkation except by the border line of the loess and the height of adjoining Iowan areas.

It may be that the limit of the Iowan ice advance extended southwest from the region of Libson to and across the Cedar valley. The relations of the loess, the presence of paha and bowlders and a rather smooth topography led to the mapping of Iowan drift southeastward to and beyond Solon. The writers have no definite evidence of the presence of Iowan drift in this area. Kansan drift with super-Kansan "gumbo" was observed in the dissected belt bordering Cedar river, three miles northeast of Solon as described on page 195, but with no overlying till.

If the Iowan ice really occupied the plains on both sides of the river as far southeast as Lisbon and Solon, it seems necessary to suppose that it occupied the valley as well. Subsequent erosion, mantling by the loess and the gullying of the same, have removed or obscured whatever trace of the presence of the ice was left. The same is true of the slopes bordering Iowa river southwest of Solon.

Conditions on and about North Liberty plain have been carefully studied by Mr. Leighton.[65] Perhaps the most important evidence of the presence of the Iowan till is found in the electric railway cut north of Iowa river, described on page 117 (Plate VII and figure 10). Here there is a bed of till, presumably post-Kansan, overlying a crumpled bed of deeply weathered gravel. Beneath this is till regarded as Kansan. Nowhere west of Johnson county does the Iowan ice appear to have crossed or even extended to the valley of Iowa river, unless it be in the vicinity of Albion in Marshall county. The upland tract in southwestern Tama county, mapped by Professor Savage as Iowan, seems to the writers clearly Kansan.

No marginal moraine phenomena were noted along the southern border of the Iowan area. The absence of such phenomena and the erosional character of the topography for some distance

[65]Leighton, M. M., The Pleistocene history of the Iowa River Valley, north and west of Iowa City in Johnson County, Iowa, Iowa Geological Survey, Vol. XXV, (1914), pp. 103-181, 1916.

north of Iowa river permit considerable difference of opinion as to the limits of the Iowan ice sheet.

As noted above, the writers did not make a careful and detailed study of the marginal parts of the Iowan drift such as would be necessary to determine accurately its limits in all places. However, while there is so much uncertainty about the exact limits of the Iowan drift south and west of northern Delaware county, one should not lose sight of the large amount of evidence of the presence of a post-Kansan drift in the area as a whole north and west of these uncertain limits.

APPENDIX A

Tables Showing Lithologic Composition of Drift.

In making analyses one hundred to seven hundred pebbles were collected from the drift at each of the places indicated. These were sorted and the percentages taken. These include numerous estimates made in 1907 by R. T. Chamberlin. Excepting the analyses by Mr. Chamberlin, careful determination of the different varieties of crystalline rock was not attempted, only the main groups being differentiated. The averages of the several types of crystalline rock are therefore only approximately correct. The totals of the several averages of the crystallines in each table would approximate the percentage of foreign material in the drift since no igneous crystalline rock formations occur in Iowa. Those nearest to the north are in Minnesota and Canada. The quartzites are probably principally from the Huronian quartzite areas of northwestern Iowa, eastern South Dakota, and southern Minnesota.

In collecting pebbles calcareous concretions and clay ironstones were generally avoided. These are not regarded as original constituents but as having formed in the drift since it was deposited. In making up the averages fractions have generally been discarded.

TABLE I.

ESTIMATE OF PEBBLES FROM THE *UNLEACHED WISCONSIN* DRIFT.
BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN, 1914-15.

	Cerro Gordo Co. Clear Lake Chamberlin	Cerro Gordo Co. Clear Lake Chamberlin	Cerro Gordo Co. Clear Lake Chamberlin	Franklin Co. West of Hampton Alden	Franklin Co. Near Coulter Alden	Franklin Co. West of Sheffield Alden	Franklin Co., East of Hampton, Outwash Gravel, Alden	Dallas Co. East of Perry Alden	Dallas Co. West of Bouton Alden	Dallas Co. West of Madrid Alden	Guthrie Co. West of Bagley Alden	Guthrie Co. East of Bayard Alden	Guthrie Co. SE. of Coon Rapids Alden	Average
Greenstone	19	16	14	22	28		11	23	21	26	21	28	20	19
Greenstone schist	1	6	2											1
Granite and gneiss	24	25	21	21	16	12	25	26	17	20	18	24	24	21
Gabbro-diorite	5	3	6											1
Syenite	1		2											
Porphyry	5	2	4	3	4	6	10			1				3
Other crystallines	5	6	7	1	22				1	1				3
Quartzite	3	3	1	1						2			4	1
Quartzose														
Quartz	1	2	3	2	2	2			1					1
Sandstone	5	3	4											1
Dolomite and limestone	29	29	30	50	50	58	47	50	60	48	61	48	52	47
Chert		1	2				7			1				1
Shale		2	1					1						
Clay ironstone														
Hematite and jasper	1	2	1							1				
Unidentified			2											

TABLE II.

ESTIMATE OF PEBBLES FROM UNLEACHED PART OF UPPERMOST TILL OF IOWAN DRIFT AREA, BY W. C. ALDEN AND M. M. LEIGHTON, 1914-15.

	Bremer Co. SE. of Sumner	Bremer Co. SE. Part, on Railway	Black Hawk Co. West of Waterloo	Black Hawk Co. West of Waterloo	Benton Co. NW. of Urbana	Benton Co. West of Keystone	Benton Co. East of Van Horn	Benton Co. North of Atkins	Linn Co. SE. of Center Point	Linn Co. Sec. 29, Otter Creek	Linn Co. East of Mt. Vernon	Clinton Co. West of Clinton	Johnson Co. Near Iowa River	Benton Co. South of Vinton	Benton Co. North of Vinton	Average
Greenstone	27	24	28	27	36	14	22	24	22	16	55	14	48	33	32	28
Greenstone schist																
Granite and gneiss	24	15	16	13	20	10	16	S	25	20	10	20	11	19	17	16
Gabbro diorite	2	24														2
Syenite																
Porphyry			2	1				2	4		2	2				1
Other crystallines		5												1	5	1
Quartzite			2	2	2			4						5	7	1
Quartzose																
Quartz			4	1	2						2		7	1		1
Sandstone		1							2		6	2				1
Dolomite and limestone	47	29	44	55	40	70	53	60	38	54	25	62	29	39	31	45
Chert		2		1		4	5	2	6	8			1	2	2	2
Shale																
Clay ironstone			4				4		4	2					3	1
Hematite and jasper													3		1	
Unidentified													1			

TABLE III.

ESTIMATE OF PEBBLES FROM LEACHED PART OF UPPERMOST TILL OF IOWAN DRIFT AREA.

BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN & M. M. LEIGHTON, 1914.

	Chickasaw Co. SE. of New Hampton Chamberlin	Fayette Co. Oelwein Cut Chamberlin	Buchanan Co. Dot 13 Gravel Pit Chamberlin	Benton Co. NW. of Urbana Alden	Benton Co. W. of Van Horn Alden	Benton Co. W. of Keystone Alden	Linn Co. Sec. 29, Otter Creek Tp. Alden	Average
Greenstone	24	32	34	60	42	40	41	39
Greenstone schist	2	4						1
Granite and gneiss	24	10	12	24	22	28	10	18
Gabbro diorite	10	2	4					2
Syenite	2							
Porphyry						8		1
Other crystallines	6	2	6					2
Quartzite	2	6		5	4	2	5	4
Quartzose	2	2	4					1
Quartz	12	10	20	6				7
Sandstone		10	4	4	2		10	4
Dolomite and limestone	8	10					5	3
Chert	4	10	16		30	22	29	16
Shale		2						
Clay ironstone	4							1
Hematite and jasper								
Unidentified								

TABLE IV.

ESTIMATE OF PEBBLES FROM BUCHANAN(?) GRAVEL IN IOWAN DRIFT AREA:

BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN & M. M. LEIGHTON, 1914.

	Howard Co. SW. of Cresco Chamberlin	Chickasaw Co. SE. of New Hampton Chamberlin	Cerro Gordo Co. NW. of Mason City Alden	Chickasaw Co. West of Alta Vista Chamberlin	Bremer Co. Creek Near Tripoli Alden	Fayette Co. Oelwein Cut Chamberlin	Benton Co. Near Keystone Alden	Linn Co. NE. of Marion Alden	Johnson Co. Near Iowa River Alden	Average
Greenstone	25	14	24	26	35	12	38	28	39	27
Greenstone schist	1									
Granite and gneiss	20	24	17	34	27	20	24	32	23	26
Gabbro-diorite	5	8			7	6				3
Syenite	4		1							1
Porphyry	1	2	1		2		2			1
Other crystallines	6	10		4		8				3
Quartzite	7	4	2	2	12	14		8	5	6
Quartzose Quartz	6	18		16	10	8		2	6	7
Sandstone	2		1	4		2		4	1	2
Dolomite and limestone	3	12	54				14		12	11
Chert	8	2		14	7	8	22	26	11	11
Shale		2				4				1
Clay ironstone	1	2				12				2
Hematite and jasper										
Unidentified		2				6			3	1

TABLE V.

ESTIMATES OF PEBBLES FROM *UNLEACHED KANSAN* (?) TILL OF IOWAN DRIFT AREA.
BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN & M. M. LEIGHTON, 1914-15.

	Howard Co. Lime Springs Chamberlin	Chickasaw Co. SE. of New Hampton Chamberlin	Chickasaw Co. Near Alta Vista Chamberlin	Floyd Co. Charles City Alden	Butler Co. East of Allison Alden	Fayette Co. Oelwein Cut Alden	Fayette Co. Oelwein Cut, Partly Leached, Chamberlin	Fayette Co. Oelwein Cut, Blue-black, Chamberlin	Fayette Co. Oelwein Cut, Blue-brown, Chamberlin	Buchanan Co. East of Keene Alden	Fayette Co. Oelwein Cut Alden	Johnson Co. Near Iowa River Alden	Average
Greenstone	12	29	17	35	32	16	36	18	20	18	20	36	24
Greenstone schist	4	3	2			6			2			2	2
Granite and gneiss	10	11	17	13	10	12	36	9	14	20	28	5	16
Gabbro-diorite	4	4	8				4	1	2				2
Syenite		4											
Porphyry			1		4								
Other crystallines	2	10	9					3					2
Quartzite	2	2		1	6		2			8	6	4	3
Quartzose													
Quartz	6	5	2	4	6	2	2	3	2	4		11	4
Sandstone	2	2	6			2		5	4				2
Dolomite and limestone	42	26	27	42	34	58	18	51	52	50	40	31	39
Chert	4	1	5		4	4		5			4	8	3
Shale	8							3	2				1
Clay ironstone		1						2					
Hematite and jasper									2				
Unidentified	4	3	6		4		2	1			2		2

TABLE VI.

ESTIMATES OF PEBBLES FROM THE *LEACHED* AND OXIDIZED UPPER PART OF THE KANSAN TILL OUTSIDE OF IOWAN DRIFT AREA.

BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN & M. M. LEIGHTON, 1914-15.

	Warren Co. Churchville Chamberlin	Warren Co. Churchville Chamberlin	Warren Co. Churchville Chamberlin	Wapello Co. Riverview Chamberlin	Marshall Co. S. of Marshalltown Chamberlin	Marshall Co. SE. Part Alden	Tama Co. West of Vining Alden	Winneshiek Co. East of Calmar Chamberlin	Union Co. Afton Junction Leighton	Average
Greenstone	10	6	10	16	30	34	22	16	27	19
Greenstone schist	2	2	2		4				2	1
Granite	15	10	14	12	12	30	16	26	15	17
Gabbro-diorite	1	4	4	16	8			14		5
Syenite	2			2	2			8		2
Porphyry							4			1
Other crystallines	9	6	2	2				6	9	4
Quartzite	14	40	32	10	4	6	6	6	20	15
Quartzose	6	2	2	4	2					2
Quartz	8	14	10	4	6			14	5	7
Sandstone	4	2	2	16				6		3
Dolomite and limestone	3				2	12	6			3
Chert	20	12	20	8	22	12	42		4	16
Shale	2		2	2	4		4		8	2
Hematite and jasper						6				1
Unidentified										

TABLE VII.

ESTIMATES OF PEBBLES FROM THE *UNLEACHED KANSAN* TILL OUT SIDE OF THE IOWAN DRIFT AREA.
BY R. T. CHAMBERLIN, 1907, AND W. C. ALDEN & M. M. LEIGHTON, 1914-15.

	Union Co., Thayer. Chamberlin	Union Co., Afton Junction. Chamberlin and Leighton	Lucas Co., NE. of Chariton. Alden	Wapello Co. Chamberlin	Wapello Co., Agency, Oxidized Till. Chamberlin	Wapello Co., Agency. Chamberlin	Iowa Co., SE. Part. Alden	Marshall Co., South of Marshalltown. Chamberlin	Marshall Co., SW. Part. Alden	Marshall Co., SE. Part. Alden	Marshall Co., SE. Part. Alden	Tama Co., NE. of Gladstone. Alden	Tama Co., West of Vining. Alden	Poweshiek Co., North of Victor. Alden	Iowa Co., NE. of Victor. Alden	Clinton Co., E. of Oxford Junction. Alden	Clinton Co., E. of Lost Nation. Alden	Clinton Co., W. of Delmar. Leighton	Clinton Co., E. of Delmar Junction. Alden	Clinton Co., 10 Miles N. of Clinton. Alden	Muscatine, 3d & Main Streets. Alden	Average
Greenstone	27	18	28	10	20	22	34	22	16	36	18	34	33	42	29	26	20	46	42	12	18	27
Greenstone schist	2	2						6										4				1
Granite	14	8	25	8	18	8	18	22	18	14	14	16	11	11	8	14	16	8	18	7	12	14
Gabbro-diorite	3	3		2	14	8		4														2
Syenite																						
Porphyry				2	4	2	1			2		5								7		1
Other crystallines	1	5	3	10	2	4								3	6						4	2
Quartzite	13	15	6	4		8	1	6	4	4		2		3	7	2	10	6	2		4	5
Quartzose	1	1		2	4	4																1
Quartz	1				6	12	1		6						1	4		2	1		4	2
Sandstone	1	3		6	4	12		4				1					4		5	6		2
Dolomite and limestone	32	39	38	42	16	14	28	34	56	30	42	23	31	29	35	50	46	30	19	38	46	34
Chert	3	2		8	4		15	2		12	22	17	20	7	3	4	4	4	13	30	12	9
Shale	1				2																	
Clay ironstones	2	4		6	2	2	2				4			4	11							2
Hematite and jasper					4	4																
Unidentified										2		2		1	1							

TABLE IX.

ESTIMATES OF PEBBLES FROM SUB-AFTONIAN OR NEBRASKAN TILL.

BY R. T. CHAMBERLIN, 1907, WM. C. ALDEN, 1914, AND M. M. LEIGHTON, 1915.

	Fayette Co. Oelwein Cut Chamberlin	Union Co. Afton Jct. Chamberlin	Union Co. Afton Jct. Chamberlin	Clinton Co. E. of Delmar Jct. Alden	Clinton Co. W. of Delmar Leighton	Average
Greenstone	8	16	16	26	42	21
Greenstone schist		2	2		2	1
Granite and gneiss	22	12	16	22	6	16
Gabbro-diorite		6				1
Syenite						
Porphyry						
Other crystallines					6	1
Quartzite			2	11	6	4
Quartzose						
Quartz	10	2	4	3	2	4
Sandstone	2	2	2	4		2
Dolomite and limestone	54	52	38	23	28	39
Chert		2	4	11	8	5
Shale	2	4	8			3
Clay ironstone		2				
Hematite and jasper			6			1
Unidentified		2	2			1

TABLE VIII.

ESTIMATES OF PEBBLES FROM AFTONIAN GRAVELS.

BY R. T. CHAMBERLIN, 1907, AND M. M. LEIGHTON, 1914-15.

	Union Co. Thayer Leighton	Union Co. Thayer Chamberlin	Union Co. Afton Jct. Chamberlin	Union Co. Afton Jct. Chamberlin	Union Co. Afton Jct. Chamberlin	Muscatine 3d & Main St. Leighton	Average
Greenstone	17	26	30	32	40	18	27
Greenstone schist	2		2				1
Granite and gneiss	12	24	16	28	16	14	18
Gabbro-diorite	1	4			8		2
Syenite		6			4		2
Porphyry						6	1
Other crystallines	5		6	6	2	2	4
Quartzite	2	6	4	8	4	14	6
Quartzose		2	6	2	2		2
Quartz	1	2				6	2
Sandstone	1		2	2			1
Dolomite and limestone		20	14	16	16	16	14
Chert	5	4	2		8	24	7
Shale							
Clay ironstone	2	6	18	6			5
Hematite and jasper							
Unidentified							

APPENDIX B

Notes on Exposures of Super-Kansan "Gumbo" in the Kansan Drift Area.

Among the most interesting exposures of what is regarded as super-Kansan "gumbo" were those afforded by the new cuts on the Chicago, Milwaukee & St. Paul railway in adjacent parts of Story and Marshall counties where the railroad runs eastward from the Wisconsin drift area of the Des Moines lobe into the Kansan drift area. The railway runs down a creek valley and cuts the spurs of the slopes from which in places the Wisconsin drift is absent, as it has been cut away by erosion. Going east from the first road crossing west of the Marshall-Story county line the following was noted.

STORY COUNTY.

COLLINS TOWNSHIP, TOWNSHIP 82 NORTH, RANGE 21 WEST, SECTION 13, SOUTHWEST QUARTER.

1st, 2d and 3d cuts east of crossing are all in Wisconsin till, calcareous nearly or quite to top.

3d cut is 30± feet deep and the core of the spur is gray till while over that the till has grayish buff tint. This is at the block-signal.

4th cut is for the most part all in loess. In the eastern part Wisconsin gray till is banked against and over 10 + feet of loess.

5th cut, gray noncalcareous "gumbo,"—face of cut sun-checked.

6th cut, gray clay, "gumbo"(?) containing lime concretions but itself noncalcareous, sun-checked, overlying buff-yellow-brown oxidized and leached Kansan till.

7th cut for ditch on curve, yellow, oxidized Kansan till, 15 feet.

		FEET
8th cut,	Buff-brown loess	5-6
	Gray loess	4
	Dense gray "gumbo," sun-checked	15
	Rusty till, Kansan, slightly exposed.	

9th cut for ditch at electric signal at county line:

	FEET
Gray loess	4-5
Yellow, oxidized till, Kansan	10

MARSHALL COUNTY.

EDEN TOWNSHIP, SECTION 19 (TOWNSHIP 82 NORTH, RANGE 20 WEST).

10th (big cut):	FEET
Buff, calcareous till, Wisconsin	8
Gray loess, contorted streaks at top, fossiliferous	?
Dense, pebbleless, gray, noncalcareous "gumbo," sun-checked	?
Yellow, oxidized till, Kansan	?
Down to track and below the track in ditch as at 9th cut.	

11th, big cut across curve of old line, 60 feet (per barometer) deep at maximum (see Plate XIII):

	FEET
Loose, buff till, Wisconsin, leached 5-6 feet, calcareous below..	25
Buff loess, full of lime concretions in lower part. Irregular ferruginous line or shell 2-3 inches thick, partly cut off at base of Wisconsin	0-15
Grayish, calcareous loess	0-15
Noncalcareous gray "gumbo," containing a few small pebbles, sun-checked	7-8
Yellow, oxidized till, Kansan	5-8

More of the Kansan till is exposed to the east as the track lowers. Where twelve feet is exposed a finely glaciated limestone bowlder three by five feet in size lies in the lower part. Farther east an equally large and finely glaciated granite bowlder lies near the top of the Kansan in the lower part or at the bottom of the gray "gumbo," which is here about ten feet thick. Near the east end of the cut is a block of gray, ripple-marked sandstone (calcareous). The loess runs down the slope to the east at least as low as the track, over the "gumbo" and Kansan till. The Wisconsin is present only at the top of the deepest part of the big cut (No. 11).

East of Rhodes, Eden township, section 10, northwest quarter, and between two and three miles east of the limit of the Wisconsin drift, the following was seen near "Station 1 mile" post (figure 14).

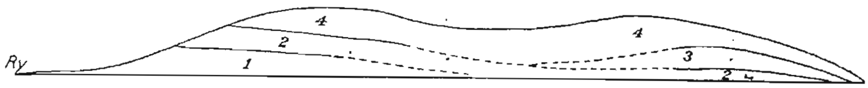


Figure 14—Diagram of drift exposed on Chicago, Milwaukee and St. Paul Railway cut east of Rhodes, Iowa. Aftonian (?) sand and gravel (1), Kansan till (2), super-Kansan "gumbo" (3), loess (4).

DRIFT EAST OF RHODES, IOWA.

	FEET
At west end of cut:	
4. Loess, buff to grayish, leached 6-8 feet, calcareous in lower part with calcium carbonate concretions	10
3. "Gumbo," dense, sticky, gray, noncalcareous clay containing some small pebbles (cut away to east by pre-loess erosion)	10
2. Till (Kansan), loose, rather sandy, rusty yellow.	
Farther east in the cut and below the loess:	
2. Till (Kansan), dark reddish to purplish brown at top, brown to grayish below, leached	6-8
1. Sand and gravel (Aftonian?), rusty, buff to brown, loose, stratified, in places cemented by iron oxide; exposed	5-8
This sand and gravel extends farther east below the track level.	

A cut one-half mile east of Melbourne exposes about ten feet of noncalcareous, gray ''gumbo'' beneath ten feet of loess.

One mile east of Haverhill (southwest quarter of section 3, Jefferson township, township 82 north, range 18 west) a cut on the Chicago, Milwaukee and St. Paul railway exposes:

DRIFT EAST OF HAVERHILL, IOWA.

		FEET
4.	Loess, buff, leached	9-10
3.	Loess, buff to gray, calcareous	5
2.	"Gumbo," dense gray clay, noncalcareous and containing a few small cherts	4-8
1.	Till, Kansan, exposed at one point.	

Between two and three miles south of this place (section 22, west line of northwest quarter) the ''gumbo'' is exposed in the road ditch below three feet of loess on the slope north of the cemetery. Here, there appears to be a gradation from the ''gumbo,'' which is gray and mottled rusty brown in the lower part, downward into the leached, rusty, grayish brown till below. In the gumbo are small pebbles, mostly cherts with some fragments of granite, feldspar, etc. In the gradation zone is a granite bowlder one foot by one and one-half feet in diameter which is crumbling to pieces and in which the feldspars are decomposing. The relations strongly suggest that the ''gumbo'' may be the product of long weathering, thorough leaching, and, finally, deoxidation of the till.

''Gumbo'' was seen also in a road cut one and one-half miles north of Haverhill and in a railroad cut east of Pickering.

POWESHIEK COUNTY.

An exposure in a road cut several miles southeast of Grinnell, Poweshiek county (Pleasant township, Township 79 North, Range 15 West, section 5, south line), showed five or six feet of dense tough ''gumbo'' near the top of a slope and thirty feet above the neighboring valley. The ''gumbo'' here is brown at the top with scattered red spots, and grayish brown below. It has a small-lump or ''buckshot'' texture. Similar ''gumbo'' was observed in a road cut at a point northeast of Grinnell (in Malcolm township, section 6, south line of southwest quarter). The ''gumbo'' here outcrops in a slope about fifteen feet from the top of the hill, which is a little lower than the upland level.

Another exposure of the "gumbo" was seen about sixteen miles farther east in a road cut on the west line of the southwest quarter of section 1, Warren township, (Township 80 North, Range 13 West) and two miles north of the railroad, near Victor. The succession in the slope just north of the southwest corner was as follows:

DRIFT NEAR VICTOR.

		FEET
4.	Loess	4
3.	"Gumbo," dense, noncalcareous clay, gray with red spots	½
2.	Till (Kansan), brown, leached	7
1.	Till (Kansan), calcareous; exposed	3

An estimate of pebbles from No. 1 is given in Table 7, Appendix A. It will be noted that it does not differ materially from the other estimates of either the Kansan or pre-Kansan drift.

IOWA COUNTY.

"Gumbo" was observed in the southeastern part of Iowa county six miles east of Parnell, near the bottom of the side slope of a small valley which cuts the north slope of the ridge between Old Man and Deer creeks (just west of the corner near the middle east line of section 3, Greene township, Township 78 North, Range 9 West). The beds exposed were as follows:

DRIFT EAST OF PARNELL, IOWA.

		FEET
3.	Loess	3-5
2.	"Gumbo," dense, brown at top, gray below, noncalcareous, contains a few small pebbles	3
1.	Till (Kansan), reddish brown, leached.	

No boring was made to determine whether or not the gumbo extends back into the hill between the loess and the till. The "gumbo" here is sixty feet or so below the level of the highly oxidized top of the till exposed on top of the ridge one mile west, and is somewhat lower than the weathered top of the till exposed in the north-south road farther south.

Four miles south (west line northwest quarter section 27) a road cut along the side slope about twenty feet below the top of the ridge exposed:

DRIFT SOUTHEAST OF PARNELL, IOWA.

		FEET
3.	Loess, buff	
2.	"Gumbo," noncalcareous clay, upper 1-1½ feet brown with red spots, gray below....................................	5-6
1.	Till (Kansan), brownish yellow, leached.	

Two miles northwest of this place (middle east line section 19) "gumbo" is exposed at about the same elevation but the cut is near the foot of the slope east of the creek and is sixty feet lower than the top of the ridge less than one-half mile north. The beds here are as follows:

DRIFT SOUTHEAST OF PARNELL, IOWA.

		FEET
3.	Loess	
2.	"Gumbo," dense, gray clay, noncalcareous, contains small chert and quartz pebbles	few feet
1.	Till (Kansan), oxidized, red.	

Two miles southeast of Parnell (Fillmore township, Township 78 North, Range 10 West, section 12, west line) a road cut across a spur near the upland level exposed:

DRIFT SOUTHEAST OF PARNELL, IOWA.

		FEET
3.	Loess, buff	3
2.	"Gumbo," upper 1-1½ feet reddish, gray below............	4-5
1.	Till (Kansan), oxidized and leached.	

It thus appears that not all the occurrences of "gumbo" are at the upland level and in places neighboring exposures at higher levels show only the red or brown oxidized till beneath the loess. Possibly some of the occurrences at relatively low levels are due to redeposition afterward from the uplands, or they may be outcrops of pre-Kansan "gumbo".

WASHINGTON COUNTY.

About eight miles west of Washington, Dutch Creek township (Township 75 North, Range 8 West, section 24, south line), gray "gumbo," sticky, gritty, and noncalcareous, was observed outcropping on a slope beneath the brown loess. This clay is pebbly a short distance below the top and contains some concretions of calcium carbonate or else it grades into till of the same color and texture. A slight exposure of the "gumbo" was seen about one mile west of Washington and another about nine miles southeast of the same place.

JOHNSON COUNTY.

About three miles northeast of Solon (Cedar township, Township 81 North, Range 5 West, section 7, east line northeast quarter), the following was seen:

DRIFT NORTHEAST OF SOLON.

		FEET
3.	Loess, buff	10
2.	"Gumbo," dense sticky, dark gray clay, noncalcareous and containing scattered small chert and quartz pebbles	5
1.	Till (Kansan), rusty brown, leached.	

About one-fourth mile northwest, around the corner (on the north line of the northeast quarter of section 7) the road cut exposes only loess, but a boring in the bottom, together with the cut, showed the same succession of deposits as that noted above.

A well on top of the ridge to the south was said by the owner to penetrate 228 feet of drift, mostly clay with sand at the bottom. Some wood was encountered about 200 feet from the surface, or about 150 feet lower than the "gumbo." W. Verba's well in section 6 is reported[66] as being drilled through the following deposits:

LOG OF W. VERBA'S WELL.

		FEET
4.	Reddish clay (loess or Kansan?)	20
3.	Blue clay, yellow, sandy (Kansan?)	100
2.	Black soil (Aftonian?)	2
1.	Brownish clay and yellow clay (pre-Kansan) above rock	10

CEDAR COUNTY.

About six miles west of Tipton (Cedar county, Cass township, Township 81 North, Range 3 West, section 31, south line of southwest quarter) a shallow road cut on the nearly flat upland exposes rusty, ashen-gray, pebbly clay with the texture and appearance of "gumbo." In a boring here the auger penetrated the following:

DRIFT WEST OF TIPTON, IOWA.

	FEET
Brownish gray pebbly clay, "gumbo"?	4
Till (Kansan?), brown, leached	3
Till (Kansan?), brown, calcareous.	

It is suggested that this gently undulating plain, some fifteen square miles in extent, which has been mapped as Iowan, may be a remnant of the Kansan upland whose dissection has been retarded by the gorge cutting of Cedar river between Cedar Bluff

[66]U. S. Geol. Survey Water Supply Paper 293, p. 425.

and Rochester and by the tributary streams having to work so much in limestone. Most of the surrounding area and especially that to the south, is much dissected, with 50 to 150 feet of relief.

About four miles southwest of Lowden (Springfield township, Township 81 North, Range 1 West, section 16 near center) a road cut on the lower part of a small spur showed, below three and one-half feet of loess, two and one-half feet of "gumbo," reddish brown, noncalcareous, with "buckshot" texture and containing sand grains and a few small pebbles.

A small exposure of "gumbo"-like clay was seen on the west side of Cedar river, two miles west of Moscow (Muscatine county, Moscow township, Township 77 North, Range 2 West, section 8, southwest quarter). At this place, below five to fifteen feet of leached buff loess is dense, gray, noncalcareous "gumbo-" like clay two to two and one-half feet thick, which carries as many pebbles as the till below. There is a dark, carbonaceous band at the top which seems to be due to vegetal growth in an old soil. The pebbly "gumbo" grades below into brown stony till. This exposure is but twenty to forty feet above the bottom land (at 660 to 680 feet above sea level) so it probably does not correspond to the super-Kansan upland "gumbo."

CLINTON COUNTY.

Going northeast across the gently undulating plain of the so-called Clinton lobe one reaches the higher hills of the loess-Kansan tract on the north. Here is a greatly dissected area with 100 to 150 feet of relief and with steep slopes sharply cut by frequent V-shaped ravines. At many of the places where the till is exposed beneath the loess its upper part is oxidized to a deep red ferretto. In a few cuts there was seen, in place of this, a well-marked bed of "gumbo". About eight miles northeast of DeWitt (Washington township, Township 82 North, Range 4 East, section 22, east line of the southeast quarter, at 760± feet above sea level) a cut in the slope fifty to sixty feet below the upland level exposed the following:

DRIFT NORTHEAST OF DEWITT, IOWA.

		FEET
3.	Loess	6
2.	"Gumbo"(?), gray clay, a few inches, and a pebble band	½
1.	Till, deep red ferretto, exposed	1½
	Brown till leached.	

Three miles to the southeast (Center township, Township 82 North, Range 5 East, section 30, east line of the northeast quarter, at 770± feet above sea level) the "gumbo" is five feet thick. It is dense, noncalcareous, gray, and blackened at the top by carbonaceous matter which resembles an old soil. This contains plentiful small pebbles, most of which are chert and quartz although some are crystallines. Beneath lies the till. Near the middle of the south half of the same section, one-half mile distant, what appears to be the same bed of "gumbo" is slightly exposed below a grassed bank ten feet high which is probably of loess. The exposures are twenty to thirty feet below the top of the loess-mantled ridge.

In the much dissected elevated tract in the northwest part of Clinton county, at one point (Sharon township, Township 83 North, Range 1 East, section 9, middle of the south line) there was noted beneath the loess on the slope, three feet of dense, brown to gray clay containing small chert and quartz pebbles and much like the "gumbo" in texture. This grades downward into stony till. This exposure is in a cut on the steep slope, about sixty feet below the top of the ridge. Other cuts, some nearer the upland level, show only the deep red ferretto at the top of the till and beneath the loess.

JONES COUNTY.

Several miles farther west another deposit which suggested the super-Kansan "gumbo" was seen at a point two to three miles north of Oxford Junction (Oxford township, Township 83 North, Range 1 West, section 10, north line of the northeast quarter). The exposure is on the slope of a lobe of the ridge, about thirty feet below the top. Beneath three feet of brown loess is a much decayed brown gravelly drift. The granite and greenstone pebbles are so decomposed as to be readily cut through. Near the top of the drift are streaks and patches of gritty gray clay which suggests "gumbo". This clay increases in amount in the lower part of the exposure as though it were due to more thorough decomposition below the gravelly top. In the lower part of the seven foot bed it becomes a mixture of light gray and dark, rusty, brown clay full of arkosic material. This appears not to be a deposit distinct from the underlying till but is in reality the much-weathered, upper part of the till so far decomposed and with so much of the soluble material removed that it approaches in character the super-Kansan "gumbo" seen elsewhere.

Northwest of this point along the high-ridged and much dissected belt of thick drift, numerous cuts expose the deeply oxidized upper part of the till beneath the loess mantle, but no other remnant of the "gumbo" is known east of the Monticello-Anamosa road and here the "gumbo" is overlain by Iowan till.

SCOTT COUNTY.

Between four and five miles west of LeClaire, Scott county (LeClaire township, near middle of the east half of section 36, Township 79 North, Range 4 East), an interesting exposure was observed in September, 1915, as follows:

DRIFT NORTHEAST OF DAVENPORT, IOWA.

		FEET
4.	Loess, buff	10-12
3.	Loess, gray, noncalcareous, with iron oxide pipes	
2.	"Gumbo" (super-Kansan), dense, gray, noncalcareous clay, showing a fine network of rusty seams and containing a few small polished quartz pebbles and chert fragments	4-5
1.	Till (Kansan?), rusty brown, with disintegrating crystalline pebbles up to 1 foot in diameter. Lower down the color becomes lighter brownish yellow, and the till is calcareous with, in one place, a thin crust of calcium carbonate several feet long.	

The gray "gumbo" (No. 2) is different in texture from the gray loess above, being more dense and sticky and containing pebbles. It resembles the super-Kansan "gumbo" farther west. The till resembles the Kansan, and the Illinoian till is apparently absent at this point.

ROCK ISLAND COUNTY, ILLINOIS.

The upland south of Mississippi river in Rock Island county, Illinois, is considerably dissected by erosion and much of the Illinoian till may have been removed before the loess, which is one to fifteen feet in thickness, was deposited. It appears to be absent at the following places. About three miles southeast of Illinois City in Buffalo township (Township 16 North, Range 4 West), just east of the middle of the west line of section 20, the following was observed in a road cut, in September, 1915:

DRIFT IN ROCK ISLAND COUNTY, ILLINOIS.

		FEET
3.	Loess, brown, leached	3±
2.	"Gumbo," dense, gray, noncalcareous, containing small cherts and some small crystalline pebbles	3±
1.	Till, brown, leached.	

About one and one-half miles farther south just south of the middle of section 29, the following was seen:

DRIFT IN ROCK ISLAND COUNTY, ILLINOIS.

		FEET
3.	Clay ("gumbo"?), rusty gray	3±
2.	Till (Kansan?), brown, leached	5±
1.	Till (Kansan?), brownish gray with abundant limestone pebbles.	

GUMBO BENEATH ILLINOIAN TILL, LOUISA COUNTY, IOWA.

In this connection it may be noted that the Kansan drift and super-Kansan "gumbo" have been observed beneath the Illinian drift in both southeastern Iowa and western Illinois.

Certain exposures examined on the upland south and west of Wapello showed:

DRIFT IN SOUTHWESTERN LOUISA COUNTY, IOWA.

		FEET
5.	Loess, brown	8-10
4.	Till (Illinoian), brown and leached but containing limestone fragments	5-10
3.	Clay (silt or "gumbo," super-Kansan), gray, with some small pebbles	2-3±
2.	Till (Kansan), brown, leached, rusty red on joint faces	6-7
1.	Till (Kansan), brown, calcareous	5±
	Limestone.	

HENRY COUNTY, ILLINOIS.

A "gumbo" which was seen at one exposure in Henry county, Illinois, is quite certainly super-Kansan, as it is overlain by Illinoian till. The exposure is on a spur crossed by the road and east of the creek and is about seven miles south and three miles west of Cambridge, in Clover township (Township 14, Range 2 East, section 14, south line of the southwest quarter). It shows the following:

DRIFT SOUTHWEST OF CAMBRIDGE, ILLINOIS.

		FEET
4.	Clay, brown, loesslike in upper part but with small pebbles lower down. These increase in size and number downward into (3)	few feet
3.	Till (Illinoian), brown, leached in upper part, calcareous below, with calcium carbonate concretions	10±
2.	Clay (super-Kansan "gumbo"), gray, noncalcareous, sticky, containing small cherts and some lumps of rusty, ferruginous clay	5
1.	Till (Kansan), gray, calcareous, containing rusty iron oxide masses and becoming more uniformly brownish lower down.	

This occurrence taken with those cited above indicates quite surely that there is a super-Kansan "gumbo" bed underlying the Illinoian till. This is clearly distinct from any super-Illinoian "gumbo".

APPENDIX C.

Occurrences of Drift, Possibly Iowan.

WINNESHIEK COUNTY.

In a boring at a point three miles southwest of Ridgeway (in Lincoln township, Township 89 North, Range 10 West, section 28, middle of west line), the following beds were penetrated:

DRIFT SOUTHWEST OF RIDGEWAY, IOWA.

	FEET
Loam, sandy	1
Till (Iowan?), brownish yellow, leached	2½
Sand, brownish yellow, leached	3½
Silt, loesslike, gray, leached	1

CERRO GORDO COUNTY.

The only exposure seen outside the Wisconsin area in Cerro Gordo county which suggested the presence of post-Kansan till was in Portland township, section 17, southeast quarter. A road cut in the abrupt thirty-five foot slope east of Lime creek showed the following:

DRIFT BETWEEN MASON CITY AND PORTLAND, IOWA.

		FEET
5.	Soil, dark, grading into loose, buff, leached, pebbly clay	2
4.	Clay, dense, gray, pebbly, lying unevenly on No. 3	0-4
3.	Sand, in irregular streaks	few inches
2.	Clay, dense, purplish, leached, "gumbo"-like, uneven as though disturbed	0-1
1.	Till, highly oxidized, reddish, gritty, leached, pebbly. No limestone pebbles seen, granites disintegrating	5-8

Number 1 looks like the Kansan ferretto of southern Iowa. Numbers 2 and 3 were present only in the north side of the cut. The upper pebbly clay, Nos. 4 and 5, might represent a distinct till sheet later than No. 1, though this clay could not with certainty be said to be till.

FLOYD COUNTY.

The writers, in company with Prof. A. O. Thomas, examined the following section exposed at an old quarry in the southern part of Charles City:

DRIFT AT KUHNLE'S QUARRY, CHARLES CITY, IOWA.

		FEET
5.	Loam, sandy	1-2
4.	Sand and gravel, rusty, containing limestone pebbles	6-8
3.	Drift, calcareous, gray to yellow, pebbly	0-1½
2.	Gravel, rusty, clayey, containing limesteone pebbles	3-4
1.	Till, dense, calcareous, pebbly, brown at top, gray below	4±

Limestone surfaces show striæ bearing south-southeast. According to Professor Thomas, Professor Calvin, who examined this exposure with him, regarded No. 1 as Kansan till, No. 2 as Buchanan gravel, and No. 3 as Iowan drift. To the present writers it seemed very uncertain that No. 3 was a distinct deposit of glacial till.

CHICKASAW COUNTY.

A road-cut three miles south of Lawler (Stapleton township, Township 95 North, Range 11 West, section 3, west line of the southwest quarter) exposed rusty brown to yellow sand and gravel, poorly assorted, leached throughout, cemented in places at the bottom by iron oxide. At one end buff leached till, which ranges from nothing to six feet in thickness, overlies the rusty gravel and includes a bowlder of the cemented gravel conglomerate besides granite bowlders up to four feet in diameter. The relations are not very clear and the till is not certainly an entirely distinct deposit.

BREMER COUNTY.

No exposures were seen showing a recognizably distinct, later till overlying an earlier till. The phenomena are as portrayed in the general description. In boring on a hill in Warren township (Township 92 North, Range 13 West, section 34, south line of the southwest quarter), the following deposits were penetrated:

DRIFT FIVE MILES EAST OF WAVERLY, IOWA.

		FEET
5	Dark pebbly soil and yellow pebbly clay till leached (Iowan?)	3½
4.	Till, yellow, calcareous (Iowan?)	½
3.	Ashen-gray, pebbly clay till, calcareous } (Kansan?)	1
2.	Ashen-gray, sandy till, calcareous } (Kansan?)	
1.	Yellow, clayey till, calcareous	1
	Boring stopped by bowlder or bedrock.	

There is here a suggestion of a thin later till overlying the bleached, but not leached, upper part of a thin lower till. The basis for separation is, however, very slight and uncertain.

FAYETTE COUNTY.

So important has a certain section near Oelwein been regarded that it may be well to present here some of the data concerning it. The cut is on the Chicago Great Western railway, southeast of Oelwein (in Jefferson township, Township 91 North, Range 9 West, sections 27 and 28). When the cut was seen by the writers in 1914 the sides were badly obscured by slumping and vegetation excepting in the upper part. By digging at a point about 200 yards east of the north-south viaduct, the following section was made out:

DRIFT NEAR OELWEIN, IOWA.

		FEET
10.	Black soil and brown loam with occasional pebbles	1½-2
9.	A line and a lenticular accumulation of pebbles and cobbles up to 5 inches in diameter (lens 10 inches deep 4 feet long)	
8.	Till, yellowish brown, leached 3½ to 4 feet, calcareous, buff in upper 1½ feet with mottlings of brown, then changes to gray with less brown mottling for 1½ feet, then in lower 6-10 inches it becomes gray-blue with streaks and mottlings of brown, total till	7-7½
7.	Humus clay, chocolate brown, rusty brown streak separating from till above, leached, rests in basin-like depression, almost 2 feet thick at sides and 3 feet in middle	2-3
6.	Dense clay, difficult to dig, no pebbles seen larger than buckshot, most of them mere quartz grains but even these rare; clay mainly blue, but blue-black just below soil	3½-4½
5.	Dense gritty clay, occasionally rotten greenstone pebbles ¼ inch in diameter, dark green in color; leached	1±
4.	Sandy clay, pale green, occasionally a greenstone and quartz pebble ¼ inch in diameter; leached	2-3
3.	Brown sandy clay, pebbles up to 2 inches in diameter,	

	quartzite and rotten granite; leached	½
2.	Blue clay with same kind of pebbles as above..........	1
1.	Sand and gravel, leached, light brown, loose, rotten granite pebbles found in it, just exposed at bottom for....	½

Number 10 does not seem to be till but an accumulation perhaps of wind-blown dust, humus, fine material brought up by burrowing animals and only an occasional pebble such as would be expected to be brought up by them or washed in. Number 8 is not separable into two tills. It is probably all Kansan. It is true that the upper six inches to one foot is more sandy than the lower part and is slightly darker brown but not more than would be expected from the material that was last deposited by the ice and subjected to wash from its waters, to later weathering and to frost action. In places there is a slight color and textural distinction between the leached portion and the underlying calcareous part, but no sharp line can be drawn. This distinction probably is the result of leaching, leaving the leached portion slightly more sandy. Number 7 is clearly a soil zone (Aftonian). Below this the dense clays appear to be silts, the result of pond deposition and similar processes. Numbers 2 and 3 may be till but this is by no means clear.

The only indication seen by the writers that the uppermost oxidized till might be distinct was the presence at two places of three to three and one-half feet of brown or yellow sand below it. This was traceable but a short distance laterally and in itself constitutes only a very slight basis (if any) for the separation of a post-Kansan till sheet.

In July, 1907, R. T. Chamberlin examined the exposure. The following is from his notes concerning this cut:

There has been so much slumping here that much digging is necessary before the section can be made out. According to an intelligent railway foreman who was present when the cut was made (9 to 10 years ago) and who had much to do with the making of the cut, the cut was originally left as a very steep bank (vertical steam shovel bank) and the present slope is entirely due to slumping and wash. The section when fresh must have been a good one, but at the present time it can only be pieced together with much digging. A section made at a point 100 feet north of the milepost was as follows:

	Feet	In.
1. Kansan drift. Upper 8 feet yellow brown, somewhat speckled with light grayish blue mottlings. Not a very hard clay here. The upper portion has been cut off by the Iowan ice and some of that drift has mixed in. It has been leached down 5 feet. Then come 4 feet of dark bluish hard, chunky clay with the upper portion of it grading rapidly into the brownish drift above. Total thickness.............	12	
2. Aftonian.		
(a) Red brown sand 2-4 in., a highly oxidized interglacial sand.		
(b) Layer of solid humus 1 in.		
(c) Clay containing much vegetable humus. Color in upper portion dark reddish brown with a lavender cast; in lower portion ordinary rusty reddish brown. Vegetable matter chiefly in upper part. Total thickness..	1	2
Elsewhere nearby there is some variation in the thickness of this colored clay, especially in its downward gradation.		
3. Sub-Aftonian. Light grayish blue, hard clay, becoming darker below. Contains very few pebbles. Only the upper foot or two could be seen even with considerable digging on account of the great amount of wash material. Height of top of this drift above the track	8	

J. Mullin, the foreman who saw the cut dug and who has since dug six feet below the level of the track to put in tiling, says that this clay becomes darker blue and much harder below, and that it extends as one uniform formation to at least six feet below the present level of the tracks.

Apparently the portion of the sub-Aftonian seen was only the top of the unoxidized material where, like the Kansan, it has become lighter in color but not yet oxidized to brown. The clayey layer above (2c) represents the weathered portion which in the upper part has been modified by vegetable matter. Above this is the solid humus layer representing the surface upon which the interglacial gravels were laid. Upon the gravels rests the blue-black Kansan till without a soil line.

Mr. Mullin brought me a slab of peaty material one and one-half feet in diameter and about one inch thick, which came from the one inch humus layer when the cut was first dug and which (together with much more of the stuff) has lain on the old dump pile ever since. This breaks off in layers and resembles "old leather" somewhat. He has also found fragments of wood at this level.

[See Appendix A, table No. 5, for estimate of pebbles from the Kansan drift.]

One hundred feet to the south (at the 1 milepost) the reddish brown Aftonian is found in a small gully. Below this is the blue black till which may be sub-Aftonian though there is a possibility that it is Kansan, the Aftonian having been incorporated in the Kansan ice. In some respects this looks like a lens of Aftonian but there is so little of it exposed and so much slope wash about that it is uncertain.

It may be called sub-Aftonian doubtful and classified as such. There were more pebbles in this than in the topmost part of the sub-Aftonian in the last section.

[See Appendix A, table No. 9 for estimate of pebbles from the sub-Aftonian.]

Section at milepost [correction for upper part of section described above]. The upper five feet of this section are grassed and the Iowan was missed, but can be found thirty feet to the northwest. At this point are four feet of yellow brown, noncalcareous Iowan drift which does not break in chunks like the Kansan and is also fresher in appearance. Below it are two inches of yellowish sand. Then comes calcareous, yellow-brown Kansan, as described above. Hence Kansan is only seven feet thick here, though elsewhere in the cut it is usually more than this.

This cut is through a ridge of highland and hence (the topography being chiefly pre-Iowan) was likely to be subject to erosion by the Iowan ice. This is probably the reason why Kansan is found to be calcareous up to its top. The leached zone has been eroded away.

[See Appendix A, table No. 5 for estimate of pebbles from the Kansan.]

The first cut two-thirds mile from the station shows the Iowan drift to better advantage than the deeper cut farther on, for the steam shovel has been in here recently. The section is:

	FEET	IN.
1. Surface soil		20
2. Yellow-brown Iowan drift. More sandy than the Kansan, noncalcareous throughout	2	
3. Bright yellow Buchanan interglacial sand		14
4. Kansan drift, grayish brown to yellow-brown just below the sand. Calcareous to the very top. Lower portion buried under talus. To the railroad tracks	10	

The Kansan is streaky in color and breaks off in chunks; the Iowan is uniform in color and though hard does not break into chunks.

[See Appendix A, table No. 3 for estimate of pebbles from the Iowan.]

One hundred yards farther on the Iowan becomes more varied in color, being yellow, brown, and gray in patches. It is very hard, especially when dry, but does not break in chunks like the Kansan. It is noncalcareous.

The Buchanan interglacial sand here becomes quite gravelly. The section is:

		FEET
1.	Hard, tenacious, yellowish brown, or grayish brown Iowan drift. Thickness including surface soil	6
2.	Buchanan sands and gravels	2-2½
3.	Brownish Kansan drift to tracks	7

[See Appendix A, table No. 4 for estimate of pebbles from the Buchanan gravel.]

The following is a description by Prof. S. W. Beyer[66a] from an examination of the cut soon after the excavation was made.

Oelwein Section.—The cut on the Chicago Great Western Railway, east of the town of Oelwein, in southern Fayette county, exhibits the following series of glacial deposits:

		FEET	
5.	Bowlder clay, rather dull-yellow in color; the upper portion is modified into a thin soil layer. Large bowlders, mainly of the granitic type, are present, often resting on or partially imbedded in the deposits lower in the series. (Iowan)	0-10	
4.	Sand and gravel—not a continuous deposit; often shows water action expressed in parallel stratification lines and false bedding. The gravels are usually highly oxidized and fine textured. (Buchanan)	0- 2	
3.	Till, usually bright-yellow above, graduating into a gray-blue when dry or a dull-blue when wet, below. This deposit is massive and exhibits a tendency to joint when exposed. Decayed granitic bowlders are common. (Kansan)	3-20	
2.	(a) Sand, fine-white, well water-worn; often with a slight admixture of silt and clay (Aftonian)	0	6 in.
	(b) Vegetal layer and soil, from two to four inches of almost pure carbonaceous matter, with one to three feet highly charged with humus. The peaty layer often affords specimens of moss (Hypnum) perfectly preserved. (Aftonian)	0- 4	
1.	Till, greenish-blue when wet or gray-blue with a greenish cast when dry. Greenstones and vein quartz pebbles predominate. (Sub-Aftonian or Albertan.) Exposed	10	

[66a]Beyer, S. W., Evidence of a sub-Aftonian till sheet in northeastern Iowa; Proc. Iowa Acad. Science, Vol. IV, p. 59.

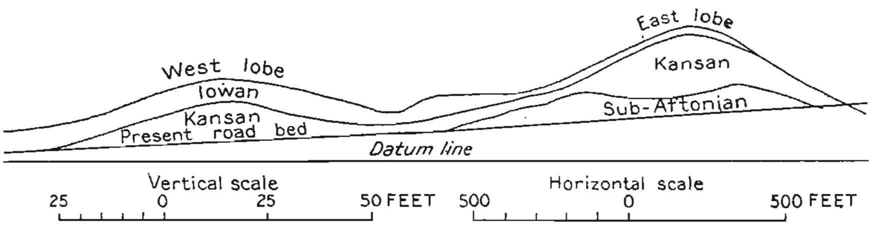


Figure 15—Diagram of deposits exposed in Chicago Great Western Railway cut southeast of Oelwein, Iowa (After Beyer).

Professor Beyer gives the above sketch of the cut (figure 15). Following the section quoted, Professor Beyer, in his paper which deals particularly with the sub-Aftonian till, makes the following statements concerning the Iowan:

The Oelwein hill trends northwest and southeast and is bilobed. The divisions will be referred to in the present paper as east and west lobes.

The Iowan reaches its maximum development near the summit of the west lobe, where it attains a thickness of some ten feet. The deposit thins eastward. At the crest of the east lobe little more than a foot of Iowan till is present, while at the extreme eastern limit of the cut Iowan bowlders are partially imbedded in the Kansan. The till varies from a pale yellow to a moderately bright yellow color, and is not thoroughly leached nor oxidized. The Iowan shows a tendency to crumble on exposure, which is in striking contrast to the older drift sheets.

The line of separation between the Iowan and Kansan is not as well marked, in all cases, as could be desired, but in most instances can be traced with some degree of confidence. In the west lobe a layer of sand sharply divides the two sheets for a distance of 100 feet, but when followed in either direction becomes much disarranged by the latter and in some places entirely loses its identity.

The Kansan is the predominant sheet in the cut and the topographic features of the region are faithfully depicted by the stiff bowlder clay of this deposit. Its maximum exposure is in the east lobe, where it exhibits a thickness of twenty feet. The upper portion is oxidized to a bright yellow, sometimes brownish-yellow, often closely resembling the Iowan in color. The most distinctive feature in its separation from the latter is the character of the included bowlders and the greater tenacity of the Kansan till. The Iowan pebbles and bowlders are prevailingly of the granite type and well preserved, while in the Kansan, greenstones are common and many of the granites are in an advanced state of decay. A granitic bowlder more than a foot in diameter was noted which had been cleaved by the steam shovel without being loosened from its matrix. Sand bowlders, lenses and wedges anomalously distributed through the oxidized portion and often extending into the upper portion of the blue till are common features. The wedges usually maintain a more or less vertical position with their apices pointing downward. The filling material in all cases closely resembles the sand layers between the Iowan and Kansan. Oftentimes the position of the various sand forms is such as to suggest their common origin with the Buchanan. In many instances stratification lines are common. In the trough of the hill, the lower portion of the Kansan contains lime concretions similar to the loesskindchen and puppchen in great numbers. The lower three or four feet of the blue till contains wood fragments in considerable abundance in a state of almost perfect preservation. The physical properties of this portion of the Kansan are very similar to the sub-Aftonian.

[The estimates of lithologic character of the pebbles made by Mr. Chamberlin from the Iowan and Kansan and by Alden and Leighton from the Kansan do not indicate any marked lithologic difference between the Iowan and Kansan in this cut. See Appendix A, tables 3 and 5.]

DELAWARE COUNTY.

Doctor Calvin[67] reported Iowan drift as overlying Buchanan gravel at scores of points within the county. W J McGee[68] reported the discovery of buried soil and wood in wells in Greeley and southeast of Masonville in Prairie township, (Township 88 North, Range 6 West, section 35, southwest quarter of the northwest quarter), but Professor Calvin regarded these as belonging to the Aftonian horizon.[69]

BUCHANAN COUNTY.

In discussing the Buchanan gravel Doctor Calvin[70] refers to the county gravel pit near the Illinois Central railway, two miles west of Winthrop (Liberty township, Township 88 North, Range 8 West, section 4, northwest quarter), and writes:

[67]Iowa Geological Survey, Vol. VIII, p. 170.
[68]U. S. Geol. Survey Eleventh Ann. Rept., p. 520.
[69]Op. cit., pp. 164-5.
[70]Iowa Geological Survey, Vol. VIII, p. 242, 1897.

* * * The line of division between the gravel and the overlying Iowan drift is also well shown, and at the south side of the pit there are yet remnants of the interglacial soil bed. The lower ten feet of the exposure is made up of coarse, cross-bedded sand which is sharply defined from the still coarser gravel which constitutes the upper part of the deposit.

When the pit was seen by the writers in 1914 all but the upper part of the section was badly obscured. The upper part, however, was clean in part and showed the following:

DRIFT TWO MILES WEST OF WINTHROP, IOWA.

		FEET	IN.
3.	Dark brown porous loamy clay containing a few pebbles	0-3	
2.	Pebble layer very definite, looks somewhat like till in places but very thin		0-8
1.	Rusty brown stratified sand and gravel	3-6	

No trace was seen of the "interglacial soil" reported by Doctor Calvin above No. 1.

Exposures beside the road one mile east of Independence (Township 88 North, Range 9 West, section 2, northwest quarter), where Doctor Calvin found two and one-half feet of Iowan drift overlying Buchanan gravel, were examined in 1914 and showed the following:

DRIFT ONE MILE EAST OF INDEPENDENCE, IOWA.

		FEET
2.	Dark grayish to brownish sandy loam, slightly banded and inclosing scattered pebbles, small to six inches in diameter	½-2
1.	Rusty brown gravel with a little sticky, brown clay intermingled. Pebbles small to eight inches or more in diameter, mostly less than one inch. Some granites thoroughly disintegrated	3

A boring in the bottom of the excavation penetrated:

	FEET
Brown gravel	1
Brown sand	6
Buff sand	1

Limestone is exposed below a thin covering of drift in the road a short distance to the west and limestone was struck at a depth of ten feet in drilling a nearby well, so that it is probable that there is but little drift below the depth reached by the auger, that is, eleven or twelve feet from the original surface. Doctor Calvin regarded No. 1 as Buchanan gravel and No. 2 as

Iowan drift. It is not very certain, however, that the latter is glacial till.

W J McGee[71] reported buried soil and wood as having been encountered in digging wells three miles north of Independence in Washington township, (Township 89 North, Range 9 West, section 15, southwest quarter of the southeast quarter and in section 22, northeast quarter of the northeast quarter).

BLACK HAWK COUNTY.

Some exposures in Cedar Falls not far from the State Teachers College were examined. One of these is just north of the race track, in Township 89 North, Range 14 West, section 13, southeast quarter. This is at a pit in the big gravel deposit in the valley of a branch of Dry Run. The section is as follows:

DRIFT IN SOUTHEAST PART OF CEDAR FALLS, IOWA.

		FEET
3.	Clay, dark to brown, loamy, leached, containing some pebbles. Till-like in part	2½- 3
2.	Sand and gravel, buff, stratified and cross-bedded, leached	4½- 5
1.	Sand and gravel, calcareous with plenty of limestone pebbles	10±

While No. 3 is till-like in part the writers do not feel at all sure that it is glacial till. It might be the more poorly assorted part of the alluvial deposit laid down upon the gravels. The gravels also are fresh-looking, largely calcareous, and but little weathered, much less so than the typical Buchanan gravel. It is possible these gravels may be a part of the Wisconsin outwash swept down the Cedar valley and into the lower part of Dry Run valley, though they may be older.

BENTON COUNTY.

A cut on the Waterloo, Cedar Falls & Northern electric railway, one mile southeast of Urbana in Polk township (Township 86 North, Range 9 West, section 35, southeast quarter), showed a lens (seven by sixteen feet in vertical section) of gravel above and sand below, included in solid buff to brown pebbly clay till. Fifty feet farther west six and one-half feet of similar brown gravel and sand was included in the till. The till is noncalcareous over the gravel but becomes calcareous downward between

[71]U. S. Geol. Survey Eleventh Ann. Rep., pp. 489, 519.

the two deposits at a depth of eight or nine feet from the top. The relations shown in the cut suggest overriding of a deposit of sand and gravel by a readvance of the ice but afford no good evidence of a post-Kansan till deposit.

Only parts of the county along and near the Waterloo, Cedar Falls & Northern railway, the Chicago, Milwaukee & St. Paul railway, and the Chicago & North Western railway were examined in 1914.

Professor T. E. Savage[72] describes an exposure in the east bank of Mud creek in Taylor township, at the middle of the west line of section 27, which shows:

DRIFT SOUTH OF VINTON, IOWA.

		FEET
3.	Fine-grained, yellow colored clay, containing no gravel...	3½
2.	Bed of yelow drift, containing pebbles and small granite bowlders	10
1.	Drift deposit which is blue at the bottom, changes to a yellow color higher up, and at the very top is a deep red. This bed carries numerous pebbles and small bowlders of dark colored trap	8

Number 1 of the above section represents Kansan drift, the upper part of which presents the typical ferretto character. The contained greenstone pebbles and bowlders are characteristic of this ancient till. Number 2 is regarded as a deposit of Iowan drift. It is of a uniformly yellow color throughout. Its superficial portion is unleached of its calcareous matter, and its iron content is not more oxidized in one portion than another. The bed here is said to be much thicker than is usual for this till. Number 3 is a bed of loess.

LINN COUNTY.

A possible exposure of Iowan till was noted two miles west of Prairiesburg, in Boulder township (Township 86 North, Range 5 West, section 20), near the west line of the bank of a tributary of Buffalo creek, where the following was seen:

DRIFT TWO MILES WEST OF PRAIRIESBURG, IOWA.

		FEET
4.	Sandy soil	½-1
3.	Sand	3
2.	Brownish leached sandy till (Iowan?)	1-2½
1.	Gray to brown interstratified sand and gravel, granite pebbles decayed, clay ironstones present but no limestone pebbles remain	5

[72]Iowa Geological Survey, Vol. XV, p. 207, 1905.

If the sand and gravel (No. 1) is Buchanan, No. 2 might be regarded as post-Kansan though the deposit is so very thin and sandy that one could hardly be certain that it is glacial till.

JONES COUNTY.

Professor Calvin[73] described an exposure in the railroad cut just west of Amber, as follows:

DRIFT WEST OF AMBER, IOWA.

		FEET
3.	Loess	4- 5
2.	Till, yellow, with rather large pebbles and small bowlders (Iowan drift)	10
1.	Blue clay with small pebbles, clay somewhat stratified (Kansan drift)	12

It seems not improbable that the yellow till is merely the oxidized portion of the Kansan since there is gradation from one to the other with no definite line of demarcation and no evidence of an interval of exposure between, such as is afforded by the soil and "gumbo" bed found in the exposures described on page 94 as present three miles to the northwest in section 30, Wayne township.

[73]Iowa Geological Survey, Vol. V, p. 65, 1895.

PLEISTOCENE DEPOSITS BETWEEN MANILLA IN CRAWFORD COUNTY AND COON RAPIDS IN CARROLL COUNTY, IOWA

BY

GEORGE F. KAY

PLEISTOCENE DEPOSITS BETWEEN MANILLA IN CRAWFORD COUNTY AND COON RAPIDS IN CARROLL COUNTY, IOWA

Many deep cuts were made recently in connection with the improvement of the Chicago, Milwaukee and St. Paul Railway between Manilla in Crawford county and Coon Rapids in Carroll county, a distance of more than thirty miles. These cuts, some of which have a depth of more than fifty feet, furnish most interesting exposures of drift and related deposits, the study of which has enabled some phases of the Pleistocene history of Iowa to be interpreted somewhat more clearly than was possible previously.

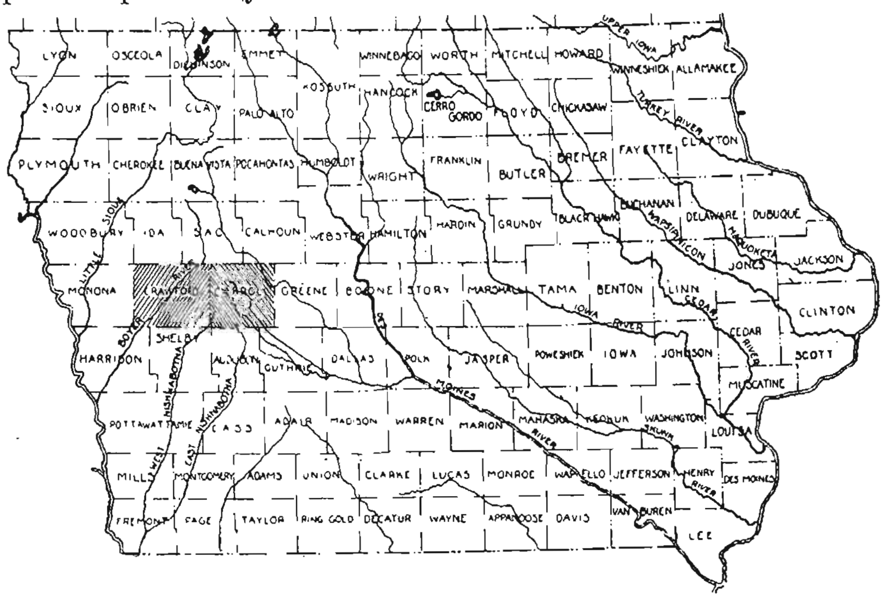


FIG. 16—Outline map of Iowa showing location of Crawford and Carroll counties.

The area through which the cuts have been made has been maturely dissected by the headwaters of Nishnabotna and Raccoon rivers, and is mantled by loess. The larger valleys have flat bottoms and maximum depths of more than one hundred feet. So thoroughly has the region been dissected that the only remnants of the uneroded uplands are a few narrow divides, which are much less extensive than the tabular divides of the maturely eroded drift areas of south-central Iowa.

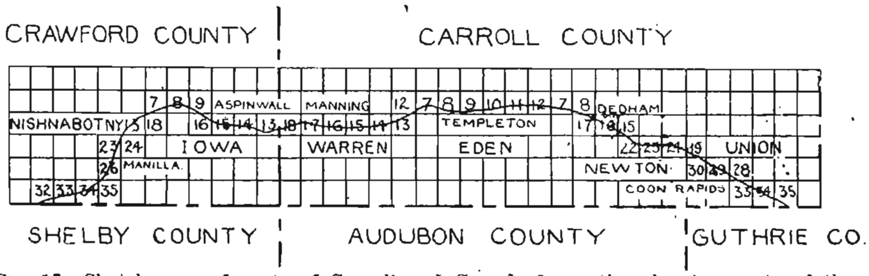


FIG. 17—Sketch map of parts of Carroll and Crawford counties showing route of the Chicago, Milwaukee and St. Paul railway.

Between Templeton and Manning in the western part of Carroll county is the main divide between the drainage of Mississippi river and the drainage of Missouri river. This divide is a remnant of a former, extensive plain, uneroded parts of which can be followed continuously southward through Audubon, Guthrie, Adair, Union and Ringgold counties into Missouri. From the south boundary of the state this uneroded upland rises gradually to the northward; at Tingley in Ringgold county its elevation is 1251 feet above sea level; at Creston in Union county, 1312 feet above sea level; at Adair in northwestern Adair county, about 1450 feet; and west of Templeton in Carroll county the elevation of the divide is nearly 1500 feet. The rise between Tingley and Templeton is about two hundred and fifty feet; the distance is about ninety miles.

The materials of this uneroded upland from the southern boundary of the state to the latitude of Templeton consist of loesslike clay or of loess, beneath which is gumbotil,[1] a gray to dark colored, leached, sticky clay, which is thought to be the result, chiefly, of the chemical weathering of drift. Beneath the gumbotil and closely related to it is a narrow zone of leached drift, below which is unleached drift with many lime concretions, the lime of the concretions having been dissolved in connection

[1]Kay, George F., Gumbotil, a New Term in Pleistocene Geology; Science, New Series, Vol. XLIV, Nov. 3, 1916.

with the formation of the overlying gumbotil and leached drift, carried downward, and later precipitated.

Since the gumbotil has not been described heretofore in these reports it is deemed desirable to reprint here the article from Science to which reference is made above. This statement is as follows:

The term gumbo has been used for many years by some geologists in America for a dense, impervious clay, which, when saturated with water, is sticky and tenacious. The name has had no relation to the origin of the material: in many cases it has been applied to alluvial deposits on the flood plains of streams: McGee, Leverett and others have applied it to a gray to drab-colored clay overlying drift, the origin of the gumbo having been attributed to various causes, some having considered it to be, mainly, of fluvio-glacial origin, others to be aqueous, and still others have thought it to be related to loess.

In a recent paper in volume 27 of the Geological Society of America, pages 115 to 117, the writer discussed a gumbo which lies on Kansan drift and which he had studied in considerable detail in southern Iowa. This gumbo is limited in distribution to tabular divides and other remnants of the Kansan drift plain. The view was there expressed that the field evidence suggested strongly that the gumbo is the result, chiefly, of the chemical weathering of Kansan drift. It was stated, also, that detailed chemical analyses of the gumbo and the underlying materials were being made by Dr. J. N. Pearce, of the chemistry department of the University of Iowa, to ascertain whether the analyses would strengthen or weaken the interpretations made from the field evidence. These analyses have now been completed and will soon be published. They seem to show clearly that the gumbo is the weathered product of the drift.

During the present summer, the writer has extended his studies into the western, northwestern and northern parts of Iowa, and at scores of places sections have been examined which show clearly the intimate relations between the gumbo and the underlying Kansan drift. Moreover, it is of interest that in many places a gumbo has been found on the Nebraskan drift, the relations of the gumbo to this drift being similar to those of the super-Kansan gumbo to the Kansan drift. Furthermore, after a somewhat careful study of the gumbo which lies on the Illinoian drift in southeastern Iowa, and which has been discussed by Leverett in Monograph XXXVIII of the United States Geological Survey, pages 28 to 33, the conclusion has been reached that here, also, the gumbo is so related to the drift that it is undoubtedly the thoroughly weathered product of the Illinoian drift.

As a result of the field investigations and the chemical studies it is now proposed that the somewhat indefinite term "gumbo" be no longer used for these super-drift clays, but that the name "gumbotil" be used. Gumbotil is, therefore, a gray to dark-colored, thoroughly leached, non-laminated, deoxidized clay, very sticky and breaking with a starch-like fracture when wet, very hard and tenacious when dry, and which is, chiefly, the result of weathering of drift. The name is intended to suggest the nature of the material and its origin, and it is thought best to use a simple rather than a compound word. Field work has already established the fact that in Iowa there are three gumbotils, the Nebraskan gumbotil, the Kansan gumbotil and the Illinoian gumbotil.

Northward from Templeton the main divide is near Arcadia, where the elevation is about 1440 feet above sea level. At Arcadia and farther northward the evidence suggests that the present summit of the divide is lower than was the surface of the original upland. Beneath the mantle of loess at Arcadia the thoroughly leached materials which are so characteristic of the uneroded uplands farther south are absent. Unleached drift with many calcareous concretions, some of which fill vertical cracks and crevices, lies directly beneath the loess. This unleached drift with concretions is similar in all respects to the zone of unleached drift with concretions in the cuts where it is overlain by leached drift and gumbotil. On a divide east of Kiron in the northern part of Crawford county is a thin remnant of gumbotil at an elevation of more than 1400 feet above sea level; at Holstein in northern Ida county, at an elevation of about 1440 feet, there is an expossure of unleached drift with many lime concretions beneath a mantle of loess. The section here is similar to that at Arcadia.

The history of northern Carroll county and farther to the north seems to have differed from the history of the Templeton region in having undergone still greater erosion. Northward from Templeton there are fewer and fewer remnants of the weathered zones until none are found. Moreover, in the region of Templeton there appears to have been more erosion than farther to the south. In south-central Iowa the uneroded remnants of upland with gumbotil and leached drift are a somewhat distinctive feature of the topography.[2]

West of the main divide between Templeton and Manning there is a narrow divide between Aspinwall and Manilla which has many of the features of uneroded upland. Still other remnants of upland occur as narrow divides between Templeton and Coon Rapids.

The new cuts show clearly that, after a mature topography had been developed in the drift, loess was deposited. It mantles the crests and slopes throughout the area to depths of five to ten feet; in places in the cuts it is more than twenty-five feet thick.

Detailed studies were made of all important cuts between Manilla and Coon Rapids. On the basis of these studies the materials have been classified as follows:

Loess.
Kansan gumbotil.
Kansan drift.
Nebraskan gumbotil.
Nebraskan drift.

In no one cut is it possible to see all of these kinds of material, nor are the two gumbotils exposed in a single cut. In some cuts the section shows loess, Kansan gumbotil and Kansan drift; in others there may be seen loess, Kansan drift and Nebraskan gumbotil; in still others, loess, Nebraskan gumbotil, and Nebraskan drift. The most comprehensive cut shows loess, Kansan drift, Nebraskan gumbotil, and Nebraskan drift. In some cuts where only loess and drift are exposed, it is not possible to determine definitely whether the drift is of Kansan or of Nebraskan age.

The most significant cuts will be described in order to show the characteristics of the different kinds of deposit, their thicknesses and relationships, and to serve as a basis for some interpretations regarding the age and history of each sort of material.

The cut through the high upland between the Mississippi river drainage and the Missouri river drainage is in section 13,

[2]Kay, George F., Some Features of the Kansan Drift in Southern Iowa: Bulletin Geological Society of America, Vol. 27, pages 115-117. Reprinted in Iowa Geological Survey, Vol. XXV, pp. 612-615.

Warren township, Carroll county, about three miles west of Templeton (figure 18). Here the section is as follows:

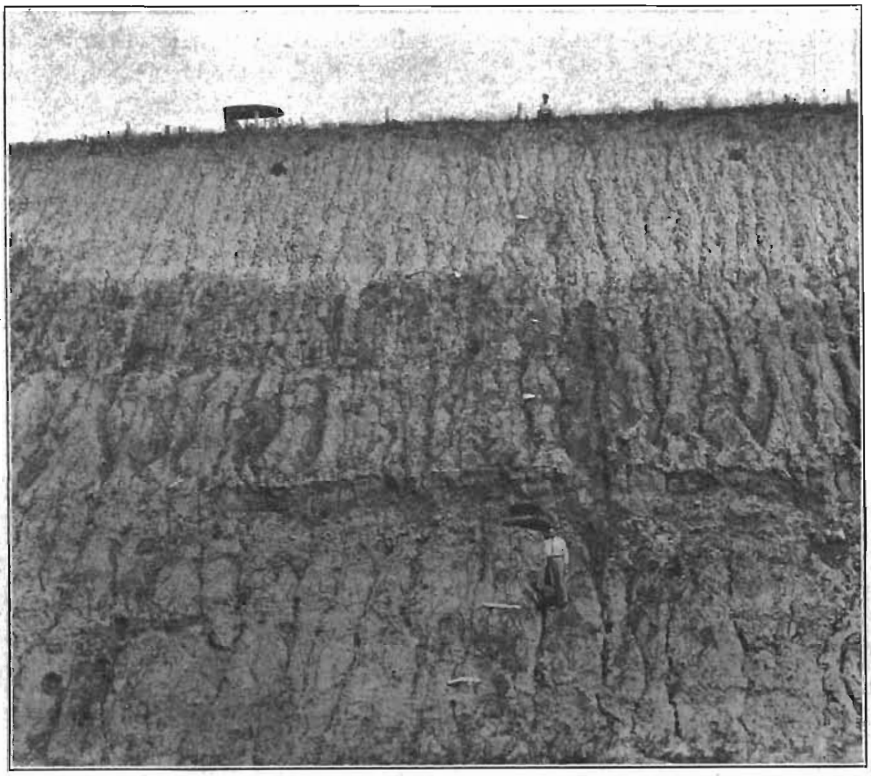


FIG. 18—Railroad cut on Chicago, Milwaukee & St. Paul railway, about three miles west of Templeton, Carroll county. This is a divide cut, and shows loess, Kansan gumbotil, and Kansan drift.

	Feet	Inches
4. Loess.		
Buff colored, leached	15	
Buff colored, unleached	10	
3. Gumbotil (Kansan), gray to dark drab to chocolate colored, upper few feet reddish, a few small siliceous pebbles	20	6
2. Drift (Kansan), oxidized yellow to buff, leached, closely related to number 3	7	
1. Drift (Kansan), oxidized, unleached; many calcareous concretions	8	

The drift in this cut is interpreted to be Kansan drift, chiefly because of its relation to the gumbotil which overlies it. This gumbotil when it is mapped southward can be shown to be continuous with gumbotil that overlies the Kansan drift of southern

Iowa.[3] The gumbotil at Templeton and the gumbotil in southern Iowa are thought from the evidence to be parts of a former, extensive, Kansan gumbotil plain. In the Templeton cut, in addition to the relation of the drift to the gumbotil, the mature erosional features of the area in which the cut is, and the nature of the materials themselves favor the interpretation that the drift is Kansan in age. That Kansan drift is distributed widely in this region was stated by Dr. H. F. Bain about twenty years ago.[4]

Between the Templeton cut just described and Manilla the only cut which has materials similar to those in the Templeton cut, and which, moreover, occupies the same topographic position as the Templeton cut is the divide cut between Aspinwall and Manilla in section 8, Iowa township (figure 19). Here is a section as follows:

		Feet
4.	Loess.	
	Buff colored, leached	12
	Buff colored, unleached, shells and concretions, lighter in color than the leached loess; lower part gray in color, but closely related to the buff loess	12
3.	Gumbotil (Kansan), dark gray to chocolate colored	3
2.	Drift (Kansan), oxidized, leached, closely related to the gumbotil, contains disintegrating bowlders	4
1.	Drift (Kansan), oxidized yellowish to buff, unleached; abundant lime concretions, many of which are in vertical joints	17

The evidence indicates that several feet of gumbotil was eroded from here before the loess was deposited. The base of the gumbotil in this cut has an elevation of about 1440 feet above sea level, which is only about twenty feet lower than the base of the gumbotil in the Templeton cut, ten miles east.

Between the two cuts that have been described there are no cuts which show Kansan gumbotil. This is because erosion prior to the deposition of the loess brought the summits below the level of the base of the gumbotil of the former, Kansan gumbotil plain.

To the east of Templeton, Kansan gumbotil and Kansan drift are present in several cuts through upland divides. One of the most interesting of these cuts is about one and three-quarter

[3]Kay, George F., Some Features of the Kansan Drift in Southern Iowa: Bulletin Geological Society of America, Vol. 27, pp. 115-117.
[4]Bain, H. F., Geology of Carroll County: Iowa Geological Survey, Vol. IX, p. 76, 1898.

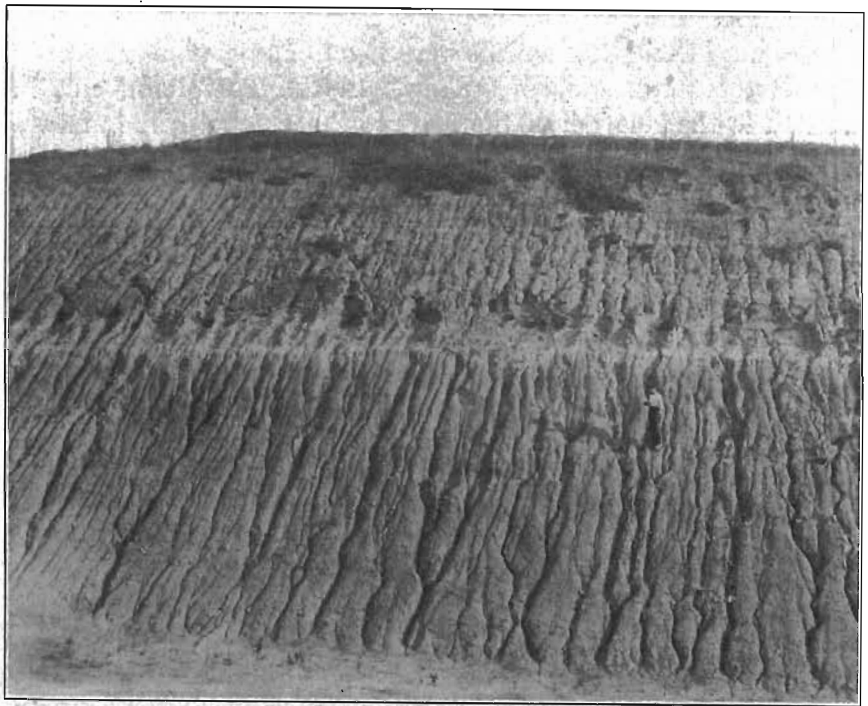


FIG. 19—Divide cut between Aspinwall and Manilla, Crawford county. The cut shows loess twenty-four feet thick, the upper twelve feet of which is leached, while the lower twelve feet is unleached. The lower part of the unleached loess is gray in color. Kansan gumbotil and Kansan drift underlie the loess.

miles west of Dedham in section 7, Newton township, Carroll county. This cut shows only a few feet of Kansan gumbotil, beneath which there is exposed the greatest thickness of Kansan drift revealed in any cut between Manilla and Coon Rapids (figure 20). This cut is known as the Green cut, and in the deepest part the following section was seen:

	Feet
4. Loess.	
Buff colored, the upper four feet leached and somewhat redder than the lower four feet, which is unleached	8
Gray, closely related to the buff loess, light colored on a dry surface; mottled chocolate colored; effervesces, but not so freely in general as the unleached buff loess; shells	6
3. Loesslike clay, leached, brownish to chocolate colored, with some pebbles; grades into number 2	1
2. Drift (Kansan), highly oxidized and leached, the upper three feet gumbotil-like	6

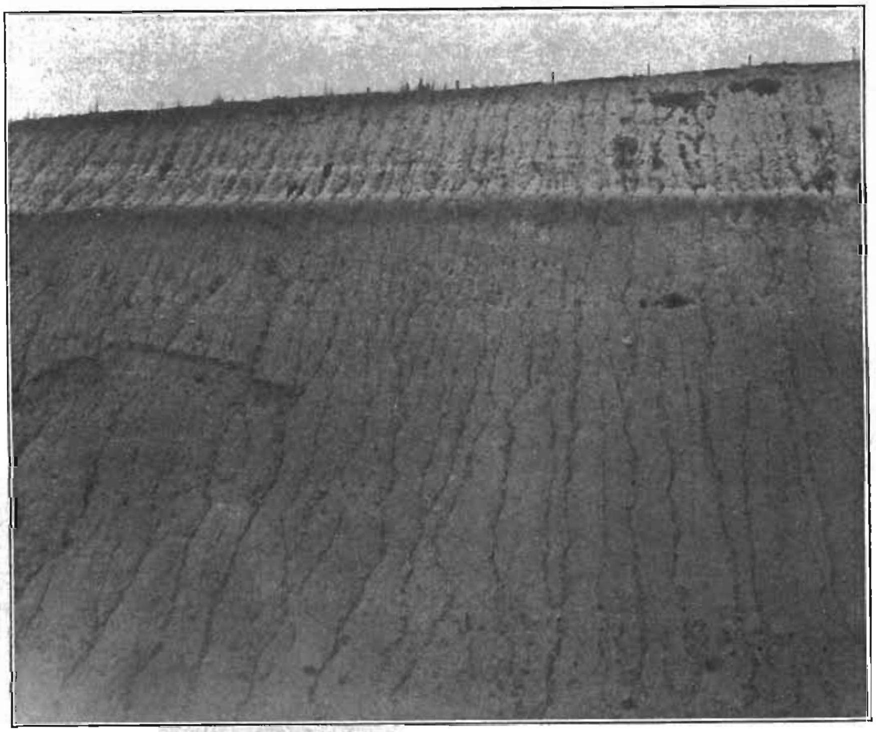


FIG. 20—Railroad cut known as Green's cut, on Chicago, Milwaukee & St. Paul railway about one and three-fourths miles west of Dedham Carroll county, Iowa. Section shows loess, Kansan gumbotil, and Kansan drift.

1. Drift (Kansan), unleached, oxidized yellowish except in lower part, where it is unoxidized and very dark colored	45

A pebble analysis by W. C. Alden of the unleached Kansan drift from here gave results as follows:

	PER CENT
Limestone and dolomite	39
Granite and diorite	26
Greenstone, diabase, etc.	20
Quartzite, mostly red	10
Quartz	1
Crystallines (identification doubtful)	2
Shale	2

About two miles east of Dedham in section 22, Newton township, Carroll county, is a deep cut (figure 21) very similar in many respects to the Green cut. Here the section is as follows:

FIG. 21—Railroad cut on Chicago, Milwaukee & St. Paul railway about two miles east of Dedham, Carroll county, Iowa. Cut shows loess, ferretto zone, and Kansan drift.

	Feet	Inches
5. Loess.		
Dark buff, leached	4	6
Buff, light colored, unleached, concretions and fossils.		
Gray, closely related to the buff loess; effervesces but not so freely as the buff, unleached loess. Less effervescence in the lower than in the upper part. Some seems not to effervesce at all. Where there are shells in the gray loess the effervescence is distinct.		
4. Loesslike clay, grayish, leached, grading down into number 3	1	
3. Ferretto zone with concentration of pebbles, highly oxidized, reddish	2	
2. Drift (Kansan), oxidized dark yellow, leached	5	
1. Drift (Kansan), oxidized yellow, unleached, many concretions	38	

In this cut there is no distinctive gumbotil. However, the ferretto zone is interpreted to have been formed in connection with the development of the present topography by erosion of the gumbotil plain. The gumbotil was higher topographically than is the surface of the ferretto zone.

Still farther east in the northeast quarter of section 24, Newton township, there is a cut which shows loess, Kansan gumbotil, and Kansan drift. The section is as follows:

	Feet	Inches
4. Loess, buff	A few feet	
3. Loesslike clay, dark gray on dry surface, dark brownish when damp, few pebbles; grades into number 2.		
2. Gumbotil (Kansan), grading downward into narrow zone of oxidized and leached drift	20	
1. Drift (Kansan), oxidized, unleached	5	6

In this cut there is an intimate relationship between gumbotil and drift. In the transition zone between the two there are disintegrating bowlders more than one foot in diameter.

The cuts which have been described show loess, Kansan gumbotil, and Kansan drift, and occupy topographically the highest divides of the region. Some cuts will be described below from localities where erosion has been sufficiently effective to bring their summits considerably below the elevations of the summits of the upland cuts. Here will be included the most comprehensive cut between Manilla and Coon Rapids. It shows loess and two drifts separated by gumbotil (figure 22). Its location is about one and one-half miles west of Manning in the southwest quarter of section 18, Warren township, Carroll county. Here the section is as follows:

	Feet	Inches
6. Loess.		
Leached, yellowish gray on dry surface; yellowish brown to buff-brown on damp surface; no shells or concretions	7	
Unleached, lighter colored on dry surface than the leached loess, and when damp it is buff with gray streaks. Contains shells and concretions	5	
5. Drift (Kansan), yellow, unleached, with calcareous concretions; numerous pebbles including granites, quartzites, etc. Below the oxidized, unleached drift is gray drift with a few pebbles. It is gumbotil-like, but effervesces freely. It was probably picked up from the gumbotil zone below	5	
4. Soil band (Aftonian) containing carbonaceous material		4

3.	Gumbotil (Nebraskan), gray to drab colored, few pebbles. The upper six feet is fine-grained, gray, and is less sticky and gumbotil-like than the lower seven feet, which is leached, but has some calcareous concretions.................	13
2.	Drift (Nebraskan), oxidized, apparently leached, but has calcareous concretions, upon which are films of manganese dioxide...............	2
1.	Drift (Nebraskan), unleached, oxidized, light yellowish color on dry surface, mottled brownish with gray when damp, many calcareous concretions, especially in upper ten feet.......	17

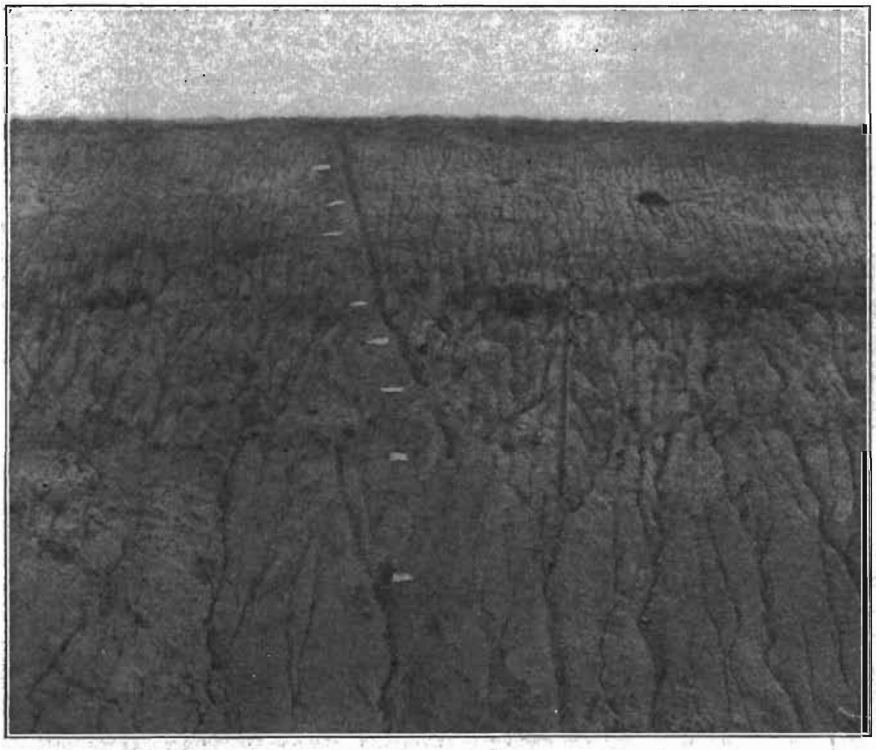


FIG. 22—Railroad cut just east of viaduct one and one-half miles west of Manning, Carroll county, Iowa. The cut shows, from the surface, the loess, Kansan drift, soil band, Nebraskan gumbotil, and Nebraskan drift.

The upper till is unleached. At this place the Kansan gumbotil and leached Kansan drift were entirely eroded in connection with the development of the preloessial topography. The history of the unleached Kansan drift here has been much the same as that of the unleached Kansan drift in those cuts already described where the Kansan gumbotil and leached Kansan drift have not been removed. The gumbotil in this cut is interpreted to be chiefly the result of weathering of the lower till. Since the upper till has been interpreted to be Kansan drift this lower till must be Nebraskan, on top of which is Nebraskan gumbotil, which was formed during the Aftonian interglacial epoch. The preloessial surface in this cut is very irregular. In places the loess lies on the Kansan drift, in places on the Nebraskan gumbotil, and in still other places on the Nebraskan drift. Pebble estimates made in this cut by Dr. W. C. Alden in the unleached Kansan drift and in the unleached Nebraskan drift gave results as follows:

	Kansan Drift Per Cent	Nebraskan Drift Per Cent
Limestone and dolomite	46	35
Granite and diorite	16	31
Greenstone, diabase, etc	19	26
Quartzite, mostly red	17	7
Chert	0	1
Red sandstone	1	0
Quartz	1	0

A cut just west from the "station one mile" post east from Aspinwall also shows the Kansan and Nebraskan drifts with intervening Nebraskan gumbotil (figure 23). The section is as follows:

		Feet
5.	Loess, yellow	4
4.	Pebble band on which is about one foot of leached, loess-like clay with small pebbles.	
3.	Drift (Kansan), oxidized and leached	4
2.	Gumbotil (Nebraskan), gray, sticky, starchlike fracture, some concretions	5
1.	Drift (Nebraskan), oxidized, in lower part calcareous	5

In the west end of this cut one foot of gray loess lies conformably below the yellow loess. A study of the pebbles in the two drifts in this cut shows more red quartzite in the Kansan drift than in the Nebraskan drift.

Another cut which shows Kansan and Nebraskan drifts with gumbotil between is the first cut east of Manilla in section 13, Nishnabotany township, Crawford county. In one part of this cut the following section was seen:

		Feet
3.	Drift (Kansan), oxidized, unleached	6
2.	Gumbotil (Nebraskan), few pebbles	3
1.	Drift (Nebraskan), oxidized, upper part leached	8

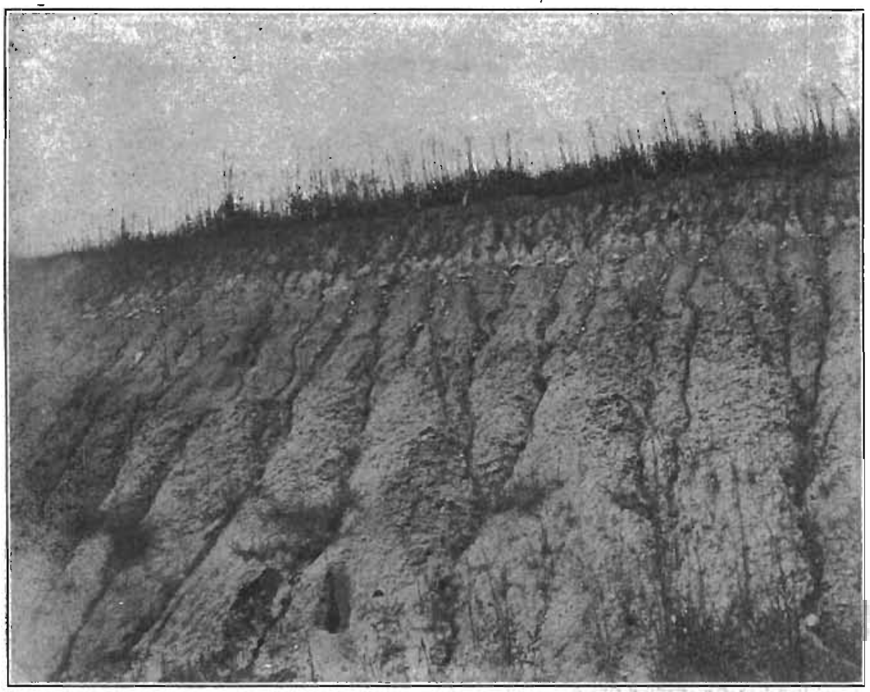


FIG. 23—Railroad cut on Chicago. Milwaukee & St. Paul railway one mile east of Aspinwall, Crawford county. The section shows loess, Kansan drift, Nebraskan gumbotil, and oxidized Nebraskan drift.

In the first big cut east of Manning in section 15, Warren township, Carroll county, is a section showing loess, calcareous till and gumbotil, the gumbotil having a very uneven upper surface apparently due to the overriding of the later ice sheet.

There is a most interesting cut one mile west from Coon Rapids. The section is as follows:

	Feet
5. Loess and loesslike clay	5
4. Drift (Kansan), oxidized, leached, concentration of pebbles at the top	5
3. Drift (Kansan), yellow, unleached, lime concretions	1
2. Gumbotil (Nebraskan), gray to drab colored, a few pebbles	5
1. Drift (Nebraskan), oxidized, unleached in lower part	2

In all of the cuts that have been described thus far either Nebraskan gumbotil or Kansan gumbotil is present. Each of these gumbotils occupies a fairly definite position in relation to the topography of the region. As has been stated already, the Kansan gumbotil is found only where the cuts are through divides which still retain approximately the elevations of the original upland plain; the Nebraskan gumbotil outcrops only in cuts whose summits are considerably below the upland level.

In the few cuts between Manilla and Coon Rapids where only gumbotil overlain by loess is found, the gumbotil, since it occurs considerably below the uplands, has been interpreted to be Nebraskan gumbotil.

The elevation of the base of the Kansan gumbotil in the cut through the main divide west of Templeton is about 1460 feet above sea level. Ten miles farther west in the divide cut between Aspinwall and Manilla the base of the Kansan gumbotil is about 1440 feet above sea level. These facts suggest that the original Kansan gumbotil plain had a gentle dip westward from the main divide. To the east of the main divide the base of the Kansan gumbotil in the Green cut, west of Dedham, has an elevation of about 1360 feet above sea level, and in a cut about two miles east of Dedham the base of the Kansan gumbotil has an elevation of about 1345 feet. Still farther east the Kansan gumbotil has an elevation of less than 1300 feet above sea level. These facts suggest that the Kansan gumbotil plain had a greater dip eastward than westward from the main divide. A study of the exposures of Nebraskan gumbotil shows that this gumbotil where it is found west of the main divide is about forty-five feet lower than the Kansan gumbotil, and has an elevation of about 1400 feet above sea level. To the east of the main divide the only cut which shows Nebraskan gumbotil is about one mile west of Coon Rapids. This cut has been described. Here the elevation of the gumbotil is about 1180 feet above sea level, and this is about one hundred feet lower than the elevation of the Kansan gumbotil in a cut three miles farther west.

In those cuts in which neither Kansan gumbotil nor Nebraskan gumbotil is exposed, but only drift overlain by loess, it has not been possible to determine whether the drift is Nebraskan drift or Kansan drift. However, where such outcrops are not far from the outcrops of Nebraskan gumbotil, and are, moreover, stratigraphically above the horizontal extension of this gumbotil, it may be fairly safe to consider that the drift is Kansan drift. There are several cuts of this nature, both east and west of the main divide (figure 24). Where cuts expose drift which occupies a topographic position lower than that of the Nebraskan gumbotil in an adjacent cut it is impossible to state definitely whether the age of the drift is Nebraskan or Kansan, although perhaps such evidence would favor the interpretation that the drift is Nebraskan drift rather than Kansan drift. There is such a cut within one mile west from Manning.

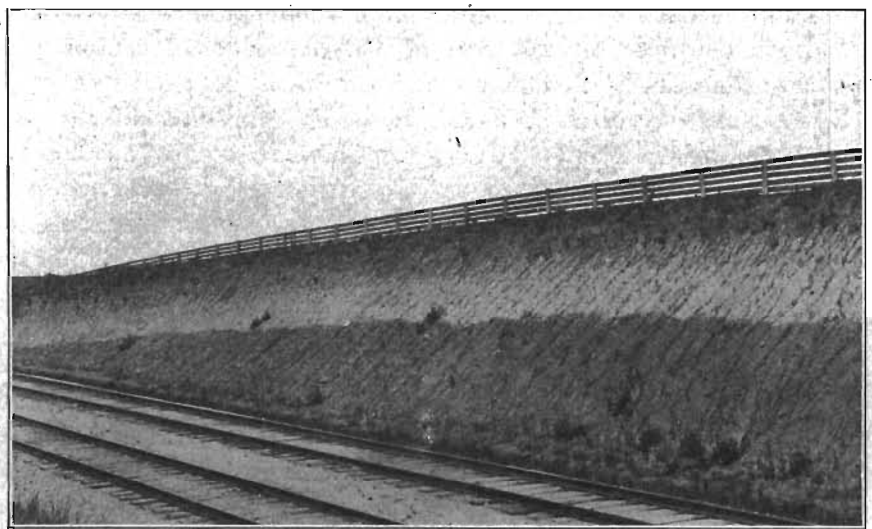


FIG. 24.—Railroad cut on Chicago Milwaukee & St. Paul railway, about one and one-half miles east of Templeton, Carroll county. The section shows loess mantling unleached, oxidized Kansan drift.

Resume.

The most significant features that have been revealed by a study of the Pleistocene deposits in many deep cuts made recently between Manilla in Crawford county and Coon Rapids in Carroll county, by the Chicago, Milwaukee, and St. Paul Railway Company, may be summarized as follows:

1. The chief kinds of material exposed are loess, Kansan gumbotil, Kansan drift, Nebraskan gumbotil, and Nebraskan drift. In no one cut is it possible to see all of these materials, nor are the two gumbotils exposed in a single cut.' In some cuts the section shows loess, Kansan gumbotil, and Kansan drift; in other cuts there may be seen loess, Kansan drift, and Nebraskan gumbotil; in still others loess, Nebraskan gumbotil, and Ne-

braskan drift. The most comprehensive cut is about one and one-half miles west of Manning. It shows loess, Kansan drift, Nebraskan gumbotil, and Nebraskan drift.

2. The two drifts, the Nebraskan and the Kansan, are much alike lithologically, and both appear to have undergone similar changes. On each of the drifts gumbotil has been developed, below which there is a narrow zone of leached drift, which grades downward into unleached drift with many concretions.

3. The maximum thickness of Nebraskan gumbotil is about thirteen feet, and of the Kansan gumbotil more than twenty feet. The zone of oxidation of the Nebraskan drift is not fully exposed in any of the cuts; the greatest depth of oxidation seen was seventeen feet. The zone of oxidation of the Kansan drift has a maximum thickness of about forty feet. Beneath this oxidized zone, in a few cuts there was seen less than ten feet of very dark, tenacious, unleached and unoxidized Kansan drift.

4. The Kansan gumbotil is limited in distribution to a few, narrow divides which are erosion remnants of a former, extensive, Kansan gumbotil plain. These divides are the present uplands of the region. The Nebraskan gumbotil is exposed only in those cuts the summits of which have been brought by erosion considerably below the elevations of the summits of the upland cuts.

5. The loess is present as a mantle over the maturely dissected surfaces. It varies in thickness from a few feet to more than twenty-five feet. In general it thickens from the crests of the ridges down the slopes, and is apparently thicker on east slopes than on west slopes. The upper parts of the ridges have been broadened more than heightened by the deposition of the loess. In places the loess lies on Kansan gumbotil; in places it is on Kansan drift; in other places it mantles the Nebraskan gumbotil, and where there has been the most extensive erosion previous to the deposition of the loess, it is on Nebraskan drift.

6. The loess has two phases, the upper of which is buff in color, the lower, gray. In many places the buff loess is leached for a few feet from the surface; in a few cuts the depth of leaching is about fifteen feet. The buff and the gray phases of the loess are closely related, and the evidence indicates that the differences are the result of chemical reactions rather than of different epochs of deposition.

THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

BY

J. ERNEST CARMAN

CONTENTS

THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

Introduction

The term, northwestern Iowa, as used in this report includes twelve entire counties and halves of four other counties; four rows from north to south, and three and one-half rows from west to east. The names and relative locations of these counties are given in figure 25. This region has an area of about 9000 square miles, about half of which was studied in considerable

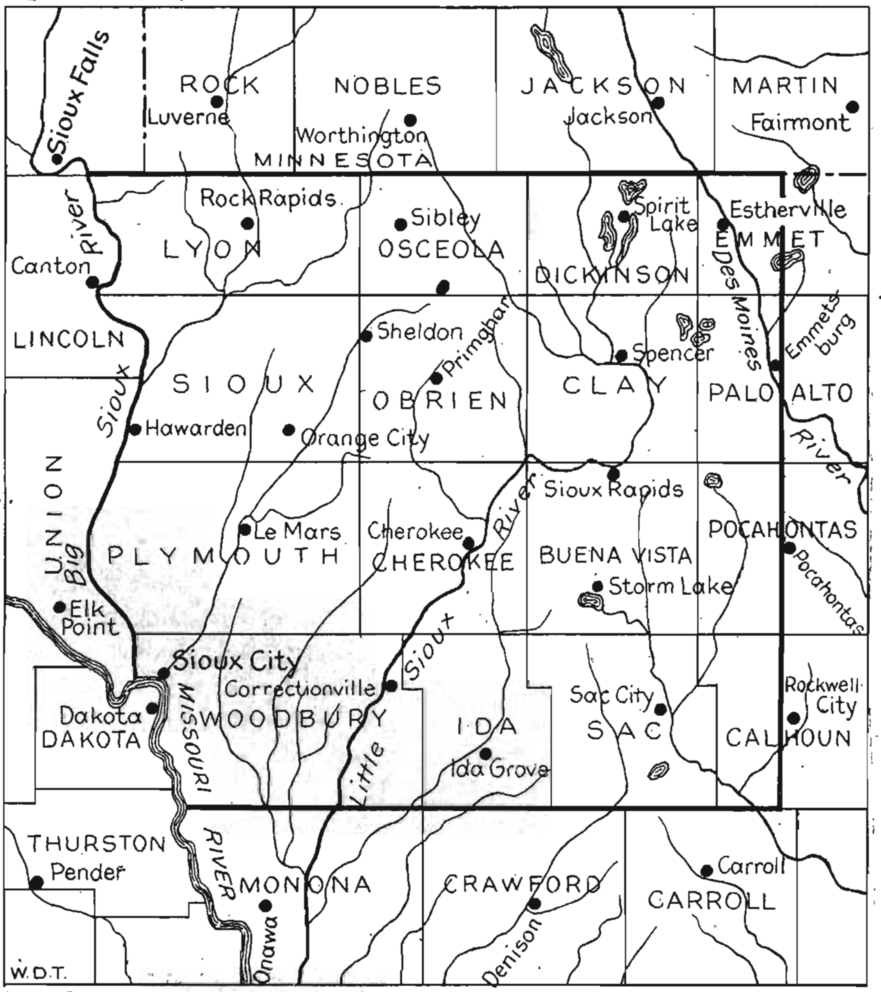


FIG. 25. ... counties and principal towns. The area treated in this report is enclosed within the heavy lines.

detail, while the remainder was covered in reconnoissance. The work also extended into the adjoining counties on the east and south and the contiguous portions of Minnesota and South Dakota, and the report will deal briefly with these areas.

The various counties of northwestern Iowa, except Calhoun county, have been studied and reported upon previously by members of the Iowa Geological Survey.[1] However, a study of these reports and the maps which accompany them will show that there were many changes of opinion during the progress of the work, and in most cases the earlier work was not revised to fit the later interpretations. Moreover, the problems of the region are largely problems involving northwestern Iowa as a whole, and hence the county-unit method of work is not suited to the region.

The work of the writer has been, therefore, of the nature of a revision and correlation of earlier work. It was begun in the summer of 1909, by retracing the west boundary of the Des Moines lobe of the Wisconsin drift-plain in northwestern Iowa. This retracing left outside the Wisconsin drift certain nearly level areas, the age of which had been variously interpreted and which it had been thought might be Wisconsin. The field work was then continued through the season of 1910, and parts of 1911, 1913 and 1916 in a study of the region west of the Wisconsin drift-boundary. This study carried the field of investigation westward to the west border of the state, and some correlation work was done in South Dakota to the west and in Minnesota to the north.

The author desires here to acknowledge his indebtedness to Professor George F. Kay, under whom, as Director of the Iowa Geological Survey, the work was completed, and to the late Professor Samuel Calvin under whose charge the work was begun; also to Mr. Frank Leverett of the United States Geological Survey, to Professors Macbride and Shimek of the Iowa Geological Survey and to Dr. James H. Lees, Assistant State Geologist. To a large number of citizens of northwestern Iowa, who have given data on their respective localities, the thanks of the author are due.

[1]Annual Reports of the Iowa Geol. Survey: Bain, Woodbury county, Vol. V, Plymouth county, Vol. VIII; Wilder, Lyon and Sioux counties, Vol. X; Macbride, Osceola and Dickinson counties, Vol. X, Clay and O'Brien counties, Vol. XI, Cherokee and Buena Vista counties, Vol. XII, Emmet, Palo Alto and Pocahontas counties, Vol. XV, Sac and Ida counties, Vol. XVI.

Northwestern Iowa is covered with glacial deposits, which almost completely conceal the bedrock. Three ice-sheets invaded the region. The area covered by the first (Nebraskan) was completely overridden by the second (Kansan) and the drift of the first is exposed only in valleys that have been cut through the overlying drift-sheet. The drift-sheets of the second and of the third (Wisconsin) ice invasions appear at the surface outside the valleys. The second ice-sheet and probably also the first covered the entire region, while the third invasion covered only the eastern part of the area.

The report begins (Chapter I) with a summary of the earlier work in northwestern Iowa. The several drifts of the region are then discussed in order from youngest to oldest. Chapter II treats the Wisconsin drift-region and Chapter III the Kansan drift-region with which is included the consideration of the loess. Chapters IV and V, on associated gravel deposits, follow the treatment of the Kansan drift, with which these deposits are closely connected. Chapter VI deals with the Nebraskan drift. Chapter VII traces the geologic history of northwestern Iowa and includes a short treatment of the bedrock. Chapter VIII restates the conclusions reached concerning the various subjects treated in the report.

In the discussion of several subjects of the report the material of a more detailed character is placed in smaller type, and may be omitted by the general reader.

CHAPTER I

EARLIER WORK IN NORTHWESTERN IOWA.

The earlier work in northwestern Iowa was of two classes: first, reconnoissance work, which dealt with large areas, chiefly the work of the earlier geological surveys of Iowa; second, somewhat detailed studies of individual counties or groups of counties, chiefly the work of the present Iowa Geological Survey.

WORK PRECEDING THE ORGANIZATION OF THE PRESENT IOWA GEOLOGICAL SURVEY.

The early geological work in Iowa was concerned principally with the bedrock of the eastern part of the state, and the superficial deposits were considered merely as obstructions to the observation of the bedrock. Owen ascended Iowa and Des Moines rivers until he passed beyond the regions of bedrock outcrops, and then turned back.[2] He shows on page 104 a sketch of the topography found on the upper course of the Iowa river (southwestern Franklin county), labeling it "Knobby drift region of northern Iowa", and states that the region is a "barren region of drift knolls." Concerning the upper part of the Des Moines river valley he says, "Beyond this (northern Webster county) the stream enters and meanders through an open prairie country, presenting to view low drift knolls" (p. 128). A party of the same survey exploring the southern tributaries of Minnesota river had found that these streams likewise head on a drift-covered region, and so it was "inferred that these barren drift knolls extend beyond the northern boundary of Iowa, covering the whole water-shed" of northern Iowa and southern Minnesota (page 104).

In the report of Hall and Whitney[3] there is very little reference to northwestern Iowa. On page 14 is this statement, "The most striking feature in the topography of the northwest is the predominance of prairies, a name--now universally adopted, to designate natural grass-land." The prairies were attributed (pages 24 to 26) to their close, fine-grained soil which was thought to be inhospitable to trees and this soil was supposed to have been accumulated in a great lake which once covered the region of the prairies.

The first comprehensive and general work on the Geology of Iowa was that by Dr. C. A. White.[4] In this report, northwestern Iowa is considered in the general treatment of the "Physical Geography and Surface Geology" (Vol. I, part 1), and in the special treatment of "Northwestern Iowa" (Vol. II, part 1, chap.

[2]Owen, D. D., Geology of Wisconsin, Iowa and Minnesota, pp. 104 and 128, 1852.
[3]Hall and Whitney. Report on the Geological Survey of the State of Iowa, Vols. I and II, 1858.
[4]White, C. A., Report on the Geological Survey of the State of Iowa, Vols. I and II, 1870.

2). The superficial deposits of the state were interpreted as the product of glacial action, but the idea of more than one glacial epoch had not yet been advanced. Northwestern Iowa is described as "generally very well drained, although a large part of it is occupied by an unusually flat portion of the Great Watershed" (Vol II, page 201).

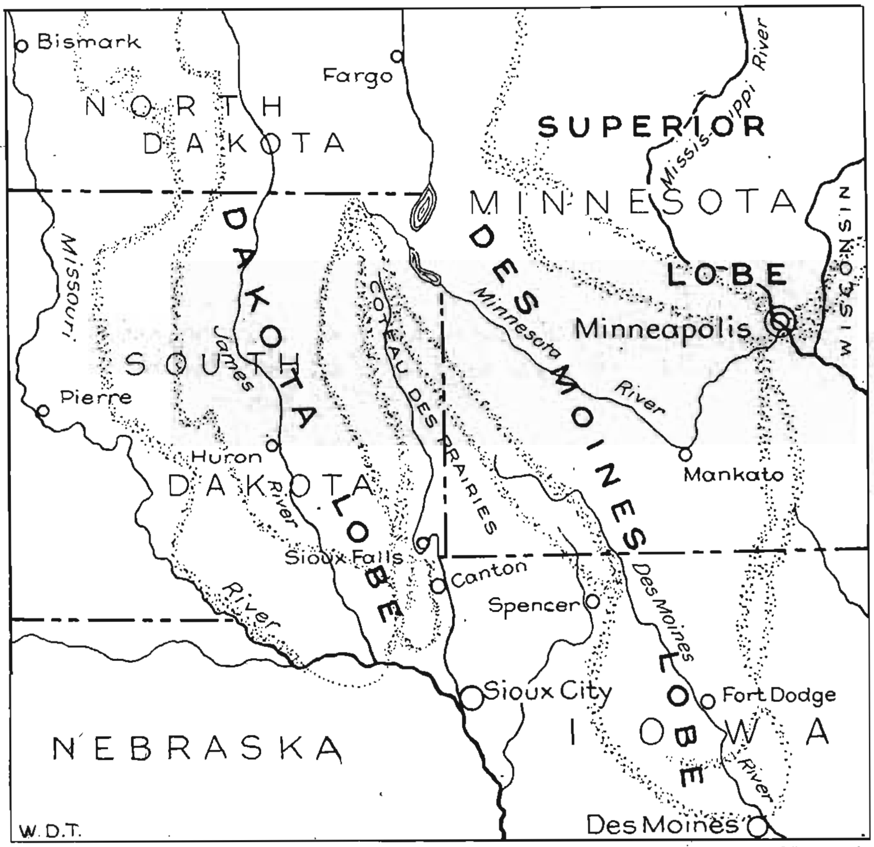


FIG. 26. Map showing the extent of the Des Moines and Dakota lobes of the Wisconsin ice-sheet. After Chamberlin, U. S. Geol. Survey, Third Ann. Rept., Plate 35.

Professor Chamberlin, during the seventies of the last century, separated the glacial deposits of America into two series, and the work of Chamberlin, Upham and Todd outlined the extent of the Minnesota-Des Moines Valley and the Dakota Valley glaciers. In his "Preliminary paper on the Terminal Moraine of the Second Glacial Epoch"[5] Professor Chamberlin

[5]Chamberlin, T. C., Terminal Moraine of the Second Glacial Epoch: U. S. Geol. Survey Third Ann. Report, pp. 291-404, 1883.

mapped the extent of and described the moraines of these lobes (figure 26). The west border of the Des Moines lobe he described as extending northward through Carroll, Sac, Buena Vista, Clay and Dickinson counties in Iowa, and continuing to the northwest through southwestern Minnesota to the head of the Coteau des Prairies. The east border of the Dakota lobe he placed west of Big Sioux river, leaving the northwest corner of Iowa as a part of the older drift-plain lying between the two lobes of the younger drift-plain.

WORK SINCE THE ORGANIZATION OF THE PRESENT IOWA GEOLOGICAL SURVEY.

The present Iowa Geological Survey was organized in 1892, and the first report of this Survey which treats of the glacial deposits of any part of northwestern Iowa is that on Woodbury county, by H. F. Bain.[6] Bain describes the topography found in the region of thick loess deposit along the Missouri as rugged (pages 248 to 249), but concerning the drift-plain farther inland he says that it is characterized by "long, low, rolling swells, flattening out into occasional broad areas of absolute level." He assigned the drift to the Kansan epoch.

In "The Great Ice Age"[7] Professor Chamberlin shows a belt of Iowan drift-plain twenty-five to thirty miles wide, extending along the whole of the western border of the Des Moines lobe. This belt includes in northwestern Iowa most of the second tier of counties east of Big Sioux and Missouri rivers. The region to the west of this Iowan belt is mapped as Kansan.

In 1896, H. F. Bain provisionally correlated the drift of northwestern Iowa, west of the Wisconsin lobe, with the Iowan drift of eastern Iowa,[8] and published as Plate XXVIII of his report, a Pleistocene map of Iowa which shows the southern "Probable Limit of Iowan Drift" in northwestern Iowa as leaving the Wisconsin moraine in northern Sac county and extending westward along the line between Ida and Cherokee counties and through southern Plymouth county to Big Sioux river about ten miles above its mouth.

[6]Bain, H. F., Geology of Woodbury County: Iowa Geol. Survey, Vol. V, pp 241-299, 1896.

[7]Chamberlin, T. C., The Great Ice Age (Geikie), Pl. 15, 1894.

[8]Bain, H. F., Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa: Iowa Geol. Survey, Vol. VI, p. 462, and Pl. 28, 1897. Calvin, S., Administrative Report: Iowa Geol. Survey, Vol. VII, p. 20, 1897.

The study of Plymouth county by Bain in 1897 was the first detailed study of the drift deposits of any part of northwestern Iowa. In this report[9] Bain discussed the lack of weathering and leaching of the drift, and the limited erosion which the region has undergone, and decided that " all the classes of evidence noted united in showing that the drift cannot be Kansan" (page 349). Either an Illinoian or an Iowan age was considered more probable, and between these two he did not decide definitely but left it "for the present", in the Iowan, to which it "has already been provisionally referred". The southern border of this Iowan area he placed farther south than on his earlier map[10] and wrote concerning it (page 351), "it can only be outlined as running from Carroll northwest through the northern tier of townships in Crawford county". Subsequent investigation evidently did not bear out this statement for in his report on Carroll county[11] Bain mapped all the area west of the Wisconsin boundary as Kansan drift.

In 1899 Professor Wilder reported on Lyon and Sioux counties.[12] The age of the loess-covered drift was still undecided, but on the map he labeled it Kansan, and after a long discussion of the subject (pages 123 to 132) concluded with the following statement, "Considering everything, it seems safer to consider the loess-covered drift of Lyon and Sioux counties as Kansan until something is found in the way of a southern boundary to distinguish it from the recognized Kansan farther south."

Professor Wilder mapped the extreme northeast corner of Lyon county as part of the Des Moines lobe of the Wisconsin drift-plain, and an area three to five miles wide, to the south and west of this, as Wisconsin outwash gravels, with great trains of the same continuing southward along the stream courses (figure 27). He also decided that the east border of the Dakota lobe pushed across Big Sioux river and occupied a narrow strip along the east side of the valley in western Lyon county. This interpretation makes the distance between the Des Moines and Dakota

[9]Bain, H. F., Geology of Plymouth County: Iowa Geol. Survey, Vol. VIII, pp. 315-366. 1898.
[10]Iowa Geol. Survey, Vol. VI, Pl. XXVIII, 1897.
[11]Bain, H. F., Geology of Carroll County: Iowa Geol. Survey, Vol. IX, pp. 49-107, 1899.
[12]Wilder, F. A., Geology of Lyon and Sioux Counties: Iowa Geol. Survey, Vol. X, pp. 85-184, 1900.

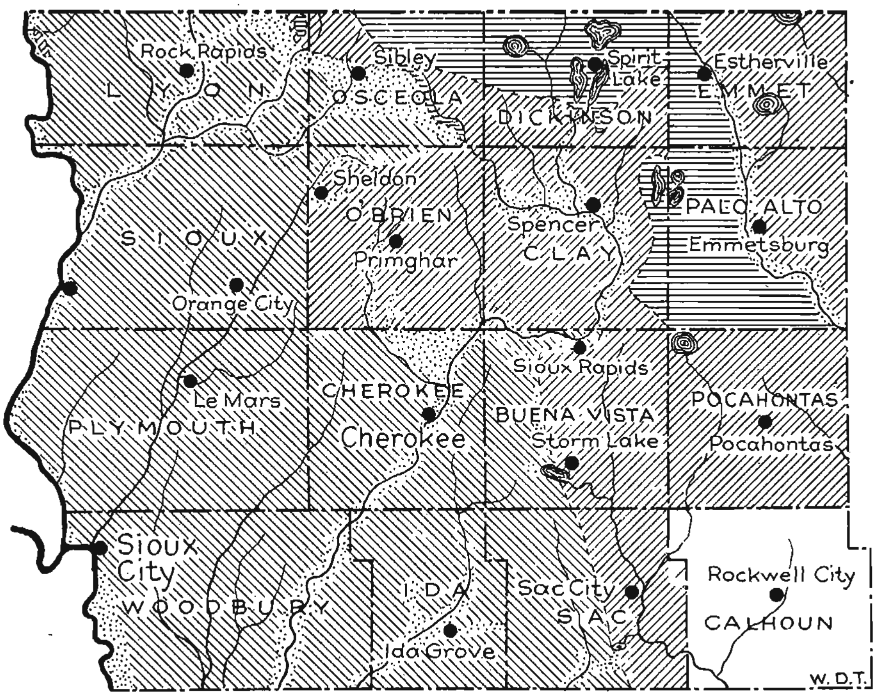


FIG. 27. A map of northwestern Iowa made by compiling the Pleistocene maps in the county reports.

"Kansan drift" of Woodbury, Ida and Sac counties; "Loess overlying older drift (Kansan)" of Cherokee and Buena Vista counties; "Loess overlying Kansan" of Lyon and Sioux counties; "Loess overlying older drift" of Osceola and O'Brien counties; "Provisionally Iowan" of Plymouth county.

"Wisconsin Drift" of Lyon, Osceola, Dickinson, O'Brien, Palo Alto, Buena Vista, Pocahontas and Sac counties; "Wisconsin Drift Plain" of Clay county; "Wisconsin Plain" of Emmet county.

"Altamont Moraine" of Lyon county; "Wisconsin Moraine" of Osceola county; "Knobby Drift, Morainic" of Dickinson county; "Knobby Drift" of Clay county; "Wisconsin Drift, affected by Morainic Knobs" of Emmet county; "Morainic Deposits" of Palo Alto county.

"Wisconsin Partially Stratified" of Lyon, Sioux, Osceola, Dickinson and Clay counties; "Wisconsin Gravel Train" of O'Brien county; "Wisconsin Overwash Gravels" of Cherokee county; "Alluvial Deposits" of Emmet, Palo Alto, Cherokee, Buena Vista and Sac counties; "Alluvium" of Ida county.

lobes less than thirty-five miles in northern Lyon county. Both these areas of Wisconsin drift are shown on the map of Lyon county and discussed in that report (pages 94 to 95, 132 to 143).

The same year Professor Macbride reported on Osceola and Dickinson counties[13] and continued the mapping units of Lyon

[13]Macbride, T. H., Geology of Osceola and Dickinson Counties: Iowa. Geol. Survey, Vol. X, pp. 185-239, 1900.

county eastward into Osceola county (figure 27). The northern part of Dickinson county, the northeast third of Osceola county, and a narrow belt along the west bluff of Ocheyedan river were mapped as "Knobby Drift" or "Wisconsin Moraine". The southern third of Dickinson county and smaller areas in southeastern and northwestern Osceola county were mapped as "Wisconsin Drift", outside the distinctly knobby areas, thus constituting extra-morainic Wisconsin drift. The area of "Wisconsin Partially Stratified" which was continued from Lyon county into Osceola, was mapped as broadening out in the central part of the county to an area six to eight miles across and then narrowing again to two to three miles where it strikes the south border of the county. The southwest corner of Osceola county was mapped as loess-covered older drift, and was referred provisionally to the Kansan epoch, (page 218).

The following year (1900) Professor Macbride reported on Clay and O'Brien counties.[14] Clay county was mapped as "Wisconsin Drift" except for a belt of "Knobby Drift" along the east border of the county and some large gravel areas along the streams (figure 27). The narrow belt of "Wisconsin Moraine", mapped along the west bluff of the Ocheyedan valley in Osceola county, and there considered a part of the Altamont moraine,[15] was not continued southward into O'Brien and Clay counties. This is true also of the area of "Wisconsin Partially Stratified". The whole of O'Brien county was mapped as "Wisconsin Drift" except a narrow wedge-shaped area in the northwest corner of the county which apparently was assigned to the "Older Drift" in order to match up with the map of Osceola county made the previous year. The "Wisconsin Drift" of the O'Brien county map joins along the west line of the county with the "Kansan Drift" of the Sioux county map.

This mapping by Professor Macbride created a large area of "Wisconsin Drift" in northwestern Iowa lying outside the Wisconsin moraine, an extra-morainic Wisconsin drift. In the same volume with the report on Clay and O'Brien counties there appeared a "Preliminary Outline Map of the Drift Sheets of

[14]Macbride, T. H., Geology of Clay and O'Brien Counties: Iowa Geol. Survey, Vol. XI, pp. 461-508, 1901.
[15]Iowa Geol. Survey, Vol. X, p. 202 and Osceola County map, 1900.

Iowa",[16] which also mapped O'Brien and Clay counties together with parts of Lyon, Osceola, Dickinson, Cherokee and Buena Vista counties as "Wisconsin" lying outside the "Wisconsin Moraine".

Subsequent work to the south evidently did not bear out the earlier conclusions concerning this extra-morainic Wisconsin area for in the report on Cherokee and Buena Vista counties[17] Cherokee county, to the south of O'Brien, was mapped as "Older Drift (Kansan)" except for a triangular area between Mill creek and the Little Sioux which was called "Wisconsin Overwash Gravel" (figure 27). The west part of Buena Vista county also was mapped as Kansan drift, which consequently abuts on the north against the "Wisconsin Drift" area of the Clay county map. The central and east parts of Buena Vista county were mapped as "Wisconsin Drift", but without a morainic belt along the boundary.

The previous assignment of the drift of O'Brien and Clay counties to the Wisconsin epoch was questioned (page 319), with the suggestion that it might prove to be earlier Wisconsin or even older. The problem was evidently considered the same as that in Plymouth county to which report "the reader is referred." In the Plymouth county report the drift had been provisionally referred to the Iowan epoch.[18]

As a part of the report on Cherokee and Buena Vista counties Professor Macbride discussed "The Margin of the Wisconsin Drift"[19] in northwestern Iowa, and mapped the course of the Altamont moraine (figure 28), a course which shows little relation to that of the same moraine on the county maps north of Buena Vista county. The age of the drift ouside the moraine was not discussed but since this drift was placed outside the Altamont moraine one would infer that it was considered as the drift of a separate ice-sheet, earlier than the late Wisconsin. However, this idea is not borne out by the next "Preliminary Outline Map of the Drift Sheets of Iowa",[20] which shows a considerable area of "Wisconsin" west of the "Wisconsin Mor-

[16] Iowa Geol. Survey, Vol. XI, Pl. 2, 1901.
[17] Macbride, T. H., Geology of Cherokee and Buena Vista Counties: Iowa Geol. Survey, Vol. XII, pp. 303-353, 1902.
[18] Iowa Geol. Survey, Vol. VIII, pp. 341-351, 1898.
[19] Iowa Geol. Survey, Vol. XII, pp. 325-338, 1902.
[20] Iowa Geol. Survey, Vol. XIV, Pl. III, 1904.

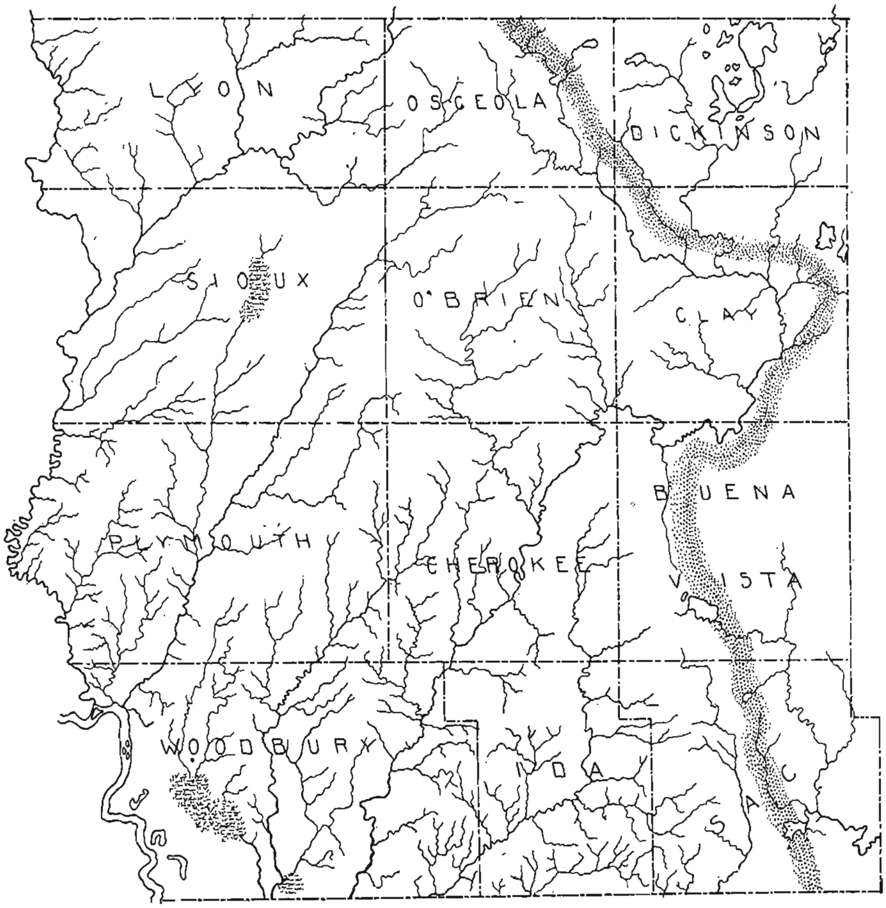


FIG. 28. Map by Professor Macbride showing the location of the Altamont moraine in northwestern Iowa. (From Iowa Geological Survey, volume XII, p. 329.)

aine." The western boundary of the "Wisconsin" area is farther east than on the earlier map,[21] but the area still includes all of Clay county west of the moraine, the larger parts of Osceola and O'Brien counties and parts of Lyon, Dickinson, Cherokee and Buena Vista counties.

The work of Professor Macbride in Sac and Ida counties[22] connected up his tracing of the Wisconsin drift boundary with the work of Bain in Carroll county to the south. The Wisconsin boundary was mapped as passing southward across central Sac

[21]Iowa Geol. Survey, Vol. XI, Pl. II, 1901.
[22]Macbride, T. H., Geology of Sac and Ida Counties: Iowa Geol. Survey, Vol. XVI, pp. 511-562, 1906.

county, dividing the county almost equally between the Wisconsin and the Kansan drifts (figure 27). The whole of Ida county was mapped as Kansan drift.

Professor Macbride also reported on Emmet, Palo Alto and Pocahontas counties.[22a] These counties are entirely within the Wisconsin drift-region. Western Emmet and Palo Alto counties were mapped as "Wisconsin Moraine" and the east parts of the counties as "Wisconsin Drift", the boundary between the two divisions being the Des Moines river valley except in the northwest township of Emmet county where the morainic area crosses to the east of the valley (figure 27). Pocahontas county to the south was assigned entirely to the "Wisconsin Drift" area, which, along the north line of the county, for more than twenty miles, abuts against the "Wisconsin Moraine" of Palo Alto county. Also along most of the west line of Emmet county and for a few miles in the northwest and southwest corners of Palo Alto county, the west lines of these counties form the boundary between the "Wisconsin Moraine" and the "Wisconsin Drift" of Dickinson and Clay counties (figure 27).

Even a cursory examination of the county reports noted above will show the lack of agreement of the county maps (figure 27) and frequent contradictions in the texts, many of which would have been avoided if larger areas had been studied before the reports were published. With the accumulation of new evidence new interpretations were adopted without showing that the earlier ones were no longer tenable. In some cases divisions were placed upon maps without discussion, and boundaries were mapped without being traced in the text, and without discussion of the characters upon which the boundaries are based. This makes it very hard to determine just what the final opinion was on certain points.

[22a]Macbride. T. H. Geology of Emmet. Palo Alto and Pocahontas Counties: Iowa Geol. Survey, Vol. XV, pp. 227-276, 1905.

CHAPTER II

THE WISCONSIN DRIFT-REGION.

During the Wisconsin Glacial epoch a great lobe of ice from the Keewatin center of central Canada occupied the basin of the Red River of the North, and advancing southward divided into two lobes at the head of the Coteau des Prairies in northeastern South Dakota. One lobe (Dakota lobe) continued southward down the James river drainage basin of eastern South Dakota, and reached the southeast corner of that state. The other (Minnesota-Des Moines lobe), passed southeastward down the Minnesota river valley to its bend in southcentral Minnesota, and then pushed southward over the divide into the Des Moines river valley, and across northcentral Iowa to Des Moines. The general extent and location of these lobes are shown in figure 26. Within the region considered in this report northeastern Osceola, most of Dickinson, and eastern Clay, Buena Vista and Sac counties belong to this drift-region (Plate XV).

General Characteristics

Topography.—The Wisconsin drift-region of northern Iowa is characterized by a distinctly glacial topography. The margins of the Wisconsin drift both on the east and on the west are more or less well developed terminal moraines, but most of this drift-region is a level or gently undulating plain. Within our area, the terminal moraine topography is well developed around the lakes of Dickinson county, in eastern Clay county, and in western Palo Alto and Emmet counties. Weaker terminal moraine is found in northeastern Osceola county. To the south in Buena Vista and Sac counties the morainic topography is faint or lacking altogether and the slightly rolling ground-moraine continues to the Wisconsin drift-boundary.

Most of the topographic features of the Wisconsin drift are constructional, consisting of moundlike hills and broad swales interspersed with undrained depressions. The relief varies from place to place, being forty to sixty feet in half a mile in the more rugged terminal moraine, and only five to ten feet in half a mile in some of the level ground moraine. The drainage of the region is youthful and lakes and marshes are numerous. Most of the broad swales have streams, but these streams did not make the valleys which they occupy. They made only the narrow channels in which they flow. Some of the larger streams have cut narrow, steep-sided valleys in the Wisconsin drift-plain, but even these streams have formed the topography of only a small part of the area they drain.

Drift.—The Wisconsin drift is light yellowish gray clay, loose, and sufficiently sandy to crumble when crushed in the hand. It contains many pebbles and bowlders which, locally in the morainic areas, make up a considerable part of the whole. Bowlders lie on the surface at many places and pebbles and gritty material appear in the soil. The till is calcareous, even to the surface, and at many places concretions of calcium carbonate are present for a few feet below the surface. The till is practically unaltered except for the incomplete distintegration of the coarse-grained igneous pebbles. In the deeper exposures the color of the till is somewhat darker than that near the surface.

The West Boundary

The position of the Wisconsin drift-boundary is one of the problems concerning which there has been much indecision, and the course as traced by the writer is, in part, quite different from that located by earlier work. This subject therefore, is treated in considerable detail. The Wisconsin drift-region to the north and east of the boundary was studied only in so far as it was thought to bear upon the interpretation of the features along the boundary.

The general results of previous work in northwestern Iowa have been given in Chapter I but that part of the work which has had to do directly with the Wisconsin drift-boundary is summarized here.

EARLIER WORK ON THE WISCONSIN BOUNDARY.

In his report on the Terminal Moraine of the Second Glacial Epoch, Professor Chamberlin described the moraine of the west side of the Des Moines lobe as extending from Des Moines "northwesterly along the middle Raccoon River, diagonally through northeastern Guthrie and central Carroll into Sac county, where it turns more northerly and extends to the southern part of Buena Vista county. Here it makes a strange easterly detour, passing curvingly through eastern Clay, central Dickinson and northeastern Osceola counties."[23]

After the organization of the present Iowa Geological Survey, H. F. Bain did considerable work along the southern portion of the western boundary of the Des Moines lobe, to the south of our region.[24] His work verified, in general, the earlier tracing by Upham and Chamberlin.

In 1898 Mr. Frank Leverett, while on a short inspection trip of the drift formations of northwestern Iowa "traced the morainic hills of the Wisconsin drift from southwestern Minnesota into the northeast corner of Lyon county".[25] The following year Wilder mapped this northeast corner of Lyon county as Wisconsin drift with patches of Altamont moraine,[26] and Macbride, continuing the same mapping units into Osceola and Dickinson counties,[27] extended the Wisconsin drift border eastward across western Osceola county just north of Sibley and Allendorf to the west bluff of the Ocheyedan river valley and then southeastward along the west bluff of this valley to the O'Brien county line (figure 27). Then followed the report on Clay and O'Brien counties,[28] which shifted the boundary to or beyond the west line of O'Brien county, and the Cherokee and Buena Vista counties report,[29] which again shifted it eastward to western Buena Vista county, and the Sac and Ida counties report,[29a] which continued the boundary southward through central Sac county.

After Professor Macbride had studied the Wisconsin drift margin from Carroll county northward to the state line he revised his previous conclusions and, in the report on Cherokee and Buena Vista counties, he discussed "The Margin of the Wis-

[23]U. S. Geol. Survey Third Ann. Report, p. 389, 1883.

[24]Annual Reports of the Iowa Geol. Survey: Bain, H. F. Relations of the Wisconsin and Kansan Drift Sheets in central Iowa, Vol. VI; Geology of Polk County, Vol. VII; Guthrie County, Vol. VII; Carroll County, Vol. IX.

[25]Bain, H. F., Administrative Report: Iowa Geol. Survey, Vol. IX, p. 26, 1899.

[26]Iowa Geol. Survey, Vol. X, pp. 132-135 and map p. 119, 1900.

[27]Iowa Geol. Survey, Vol. X. map p. 209, 1900.

[28]Iowa Geol. Survey, Vol. XI, map p. 491, 1901.

[29]Iowa Geol. Survey, Vol. XII, map, p. 355, 1902.

[29a]Iowa Geol. Survey, Vol. XVI, pp. 535-539 and map, p. 537. 1906.

consin Drift",[30] and mapped the course of the Altamont moraine from Carroll county northward to the state line (figure 28). This course is northward through Sac and Buena Vista counties to the Little Sioux valley east of the mouth of Brooke creek. It then follows the south bank of the Little Sioux valley eastward past Sioux Rapids to Gillett Grove in southeastern Clay County. From here it bears northeast to a point east of the town of Dickens, where, bending sharply to the west, it follows the north slope of the Little Sioux valley westward, passing just north of Spencer. Crossing the Little Sioux just above its union with the Ocheyedan the boundary follows the northeast slope of the latter valley through northwestern Clay and eastern Osceola counties to the state line. The course of this boundary is merely stated and the evidence upon which it is based is not given. This is Professor Macbride's final statement on the Wisconsin drift margin and thus the question stood when the writer took up the revision study in 1909.

CRITERIA FOR DISTINGUISHING THE WISCONSIN BOUNDARY.

The separation of the Wisconsin drift-region from the older drift-region to the west is based chiefly on physiographic characters and the boundary is first of all a physiographic boundary. Differences in the character of the drift and in its surface covering are contributory lines of evidence, useful when available; but when these appear to fail, physiographic differences must be used as the basis for the separation. And even with this criterion, extreme care in observation, and appreciation of the significance of certain slight differences are required.

As stated on page 251, the topography of the Wisconsin drift is largely constructional. Along part of the boundary these constructional features are prominent, being morainic hills, and depressions that are occupied by lakes and marshes. Elsewhere, because of the slight relief, the constructional features are not prominent, but they may be detected by careful observation. The most prominent topographic feature of the region west of the Wisconsin drift-boundary is its valleys, and the drainage of this region is complete. The small undrained depressions which

[30] Iowa Geol. Survey, Vol. XII, pp. 325-338 and Fig. 58, 1902.

characterize the Wisconsin drift are entirely absent. These depressions are an important character in determining the location of the Wisconsin drift-boundary.

The Wisconsin till is more sandy and therefore less compact than the Kansan till of the region to the west. When it is crushed in the hand, it crumbles to a mealy clay, while the older till as a rule is plastic. The Wisconsin till also contains a larger number of pebbles, cobbles and bowlders. Its color is gray, while the older till is buff to yellow. The differences are not such that every exposure along the boundary can be identified as Wisconsin or Kansan till, but many exposures can be so identified. Some of these will be noted in the discussion of the Wisconsin drift-boundary (pages 255 to 292).

The Wisconsin drift comes to the surface and there are pebbles and grit in the soil and bowlders on the surface. A thin mantle of leached loess covers the region west of the Wisconsin drift and conceals the till except in the more rugged parts. The Wisconsin till is practically unaltered and calcareous to the surface, but this is almost equally true for the Kansan till. The loess overlying the Kansan till, however, is at most places leached.

RETRACING THE WISCONSIN BOUNDARY.

The Boundary South of Sac County.—This report deals principally with that part of the Wisconsin drift boundary north of the south line of Sac county; but for the sake of comparison and in order to study the criteria upon which the separation was made, the boundary was examined at several places south of Sac county, in Carroll county, and even farther southeast as far as Des Moines. For most of the distance the boundary follows the northeast slope of Middle Raccoon river valley. This valley, except possibly in part of Carroll county, was a pre-Wisconsin feature and the ice-margin at some places pushed down to the edge of the stream, and was at no place more than two miles away. The stream was crowded over against the southwest slope by the ice and by the debris which came down from the ice-margin, and locally may have been diverted from its valley. The ice, however, did not fill the valley for any considerable distance.

At a few places along this valley, outwash materials came down from the ice-front to the north and were deposited on the valley slope or in the valley, where they now form benches (terraces). On the whole, however, there is very little outwash material, and although this valley received the drainage of eighty to ninety miles of the ice-margin it has no continuous gravel benches.

Northeast of the Middle Raccoon valley, youthful drift topography is continuous, while to the southwest, the maturely dissected topography of the Kansan drift-plain prevails. The topographic contrast of the two regions is pronounced through this southern district and in most places the location of the boundary is well defined, even where a valley does not mark the boundary. Furthermore, the Kansan drift has a weathered surface zone while the Wisconsin drift is fresh throughout, and most of the Kansan drift is covered with a veneer of loess, while the Wisconsin drift is without such cover.

From the South Line of Sac County to the Little Sioux Valley at the Mouth of Brooke Creek.—The general course of the boundary across Sac and Buena Vista counties is very straight with a direction 18° west of north (Plate XV). So uniform is this course, that if a straight line were drawn connecting the point at which the boundary crosses the south line of Sac county with the mouth of Brooke creek, it would nowhere be two miles from the actual boundary, and with the exception of the region south of Wall lake outlet, nowhere so much as one mile.

From the south line of Sac county the Wisconsin drift-boundary extends northwestward along the valley of a small creek to the Wall lake outlet (Plate XV). Throughout this distance the Wisconsin drift topography comes up to the east side of this little valley, while it is not present on the west. This course just south of the outlet is about one and one-half miles farther west than that traced by Professor Macbride.

Three miles north of the south line of Sac county a flat-bottomed marshy valley, about one mile wide and ninety to one hundred feet below the upland to the south, leads westward from the margin of the Wisconsin drift to the Boyer river valley, a distance of three to four miles. This valley is known as the Wall lake outlet. It is not now followed by any stream, but apparently was an outlet for drainage from the Wisconsin ice-margin westward to the Boyer valley. From its east end, a marshy flat stretches northward two miles over a low divide to Wall lake, along a course that was followed by waters draining southward along the ice-margin to the Wall lake outlet.

Where it crosses the Wall lake outlet, the Wisconsin boundary is offset a mile to the east. Thence it passes north through Lake View and west of north through western Wall Lake, eastern Boyer Valley and western Delaware townships of Sac county, and through eastern Hayes township of Buena Vista county to the southeast corner of Storm lake (Plate XV). A belt one to two miles wide along the margin of the Wisconsin drift-plain from Wall lake to the north border of Sac county has a moderately well developed terminal moraine topography, with bowlder-strewn hummocks and saucer-shaped depressions occupied by ponds and marshes.

East of the margin the region grades into a slightly rolling glacial plain, which continues up to the edge of the narrow steep-sided Raccoon river valley. Beyond this valley a slightly rolling to flat ground moraine topography characterizes eastern Sac county and continues across Calhoun county.

West of the Wisconsin drift-boundary, the region is completely drained, and presents a topography marked by broad valleys and undulating slopes. In general the region just to the west of the boundary from Wall lake outlet to Storm lake is higher than the Wisconsin drift-margin to the east.

North of Storm lake the boundary passes just east of the town of Storm Lake, and from here the valley of Brooke creek forms the boundary northward through Washington, Elk and Brooke townships to the valley of Little Sioux river (Plate XV). The contrast of the topography on opposite sides of Brooke creek in Elk township is striking. On the east is a slightly rolling glacial plain, with its rounded hills and occasional marshes, continuing up to the very edge of the valley, which at some points is hidden from view even at a distance of half a mile. On the west there is a general eastward slope cut by parallel valleys which head westward toward the broad, high area of central Elk and Brooke townships.

The boundary of the Wisconsin drift crosses the south line of Sac county near the quarter-corner on the south of section 34, Viola township, and extends northwestward along the valley of a small creek through the southwest quarter of section 34, the northeast quarter of section 33, the southwest quarter of section 28, the central part of section 29, the west part of section 20 and the southwest quarter of section 17 to the Wall lake outlet (Plate XV). The topography just east of the valley is not so definite and positive as farther east, but the features that characterize the Wisconsin drift-plain are present. In the central part of section 20, 100 yards east of the valley there is one small depression that will hold water and two others are present in the northeast quarter of section 29. Also the soil is sandy and contains pebbles.

This course through sections 29 and 20 is about one and one-half miles farther west than that traced by Professor Macbride, which extends northward through the west parts of sections 34 and 27 and the east part of section 21. East of the line traced by Professor Macbride the region is plainly Wisconsin, being a moderately rolling glacial plain with marsh areas and a few hummocky hills. Here all the pre-Wisconsin erosional features were completely obliterated. There is, however, no significant change along this course traced by Professor Macbride, and the west parts of sections 28 and 21 and the east parts of sections 29 and 20 were covered by the Wisconsin ice long enough to develop the positive glacial features noted above, but not enough drift was deposited to obliterate completely the pre-Wisconsin erosional features.

The till well within the Wisconsin area is sandy yellowish gray clay. Certain exposures along the small valley in section 20 show till that is neither typical Wisconsin nor Kansan. An exposure just west of the northeast corner of section 30, just outside the area that could be called Wisconsin on the basis of topography, may be Wisconsin till, and, considered in connection with some exposures on the east line of the northeast quarter of section 19, and some bowlders on the north line of 19, suggests that the Wisconsin ice may have crossed temporarily the valley of section 20, and occupied the east part of section 19. In this case the boundary follows a small creek valley that extends from north to south across the central part of section 19, and then passes across the northeast quarter of section 30 and the northwest quarter of section 29, to the valley in the central part of section 29. This change of the boundary could not be made on the basis of topography.

From Wall lake outlet northward within a few miles of the north border of Sac county, the boundary is along a depression, apparently a pre-Wisconsin valley, parallel with the Boyer river valley to the west. The depression is followed along most of its length by Indian creek, which flows southward, and during the time of ice occupancy it led the marginal drainage southward, past Lake View, to the head of the Wall lake outlet, which opened westward to Boyer river. This valley drained twelve to fifteen miles of the ice-margin, and the great deposits of gravel at the west end of Wall lake and south of Lake View were deposited by its waters. The east slope of Indian creek valley has a glacial topography with gravelly mounds and swamps; but the west slope is even and rises gradually to the rounded divide, fifty to sixty feet higher, which separates Indian creek from Boyer river. Farther north the ice seems to have climbed higher up this slope on the west, until in western Delaware township the divide was almost overridden, and, locally, drainage may have passed over it to Boyer river. Farther north, in section 36 of Hayes township of Buena Vista county, a steep-sided valley leaves the Wisconsin margin and extends westward through the divide. A small area of the Wisconsin drift-plain now drains westward through this valley to the headwaters of the Boyer, but when the Wisconsin ice was present, the drainage of several miles of the ice-front, from Storm Lake on the north to the county line on the south, probably drained westward through this valley.

Storm lake lies just outside the Wisconsin drift-boundary and occupies a part of a stream valley which in pre-Wisconsin time headed westward on the slope of the great watershed at Alta, and continued eastward to some western tributary of the Des Moines. When the Wisconsin ice-front lay across this valley, an ice-margin lake was formed, and when the ice withdrew, the old valley had been dammed by the morainic deposits to such an extent that the basin of Storm lake was formed. The ice-margin lake probably drained southward along the edge of the ice for three miles to the head of the valley described above, which leads westward through the divide to the headwaters of Boyer river. The present outlet from the southeast corner of the lake follows this old course southward for about two miles, and then turns eastward across the Wisconsin drift-plain to Raccoon river.

Storm lake is three miles long and one and one-half miles wide. The water is nowhere more than fifteen deep, and considerable areas near the shore are only a few feet deep, being dry or marshy in times of low water. Cliffs ten to fifteen feet high rise from the water's edge along the northwest margin of the lake, and at a few places farther east, but in general the slopes are gentle, and beaches border the lake.

Just north of Storm lake the boundary passes through the west central part of section 2, just east of town, and then northwest across section 34 and along the west line of section 27, Washington township, to the headwaters of Brooke creek in section 21. Parts of sections 28 and 33 have a slightly rolling, filled-in topography on the headwaters of some small streams. From section 21 the valley of Brooke creek forms the boundary northward through Washington, Elk and Brooke townships to the valley of Little Sioux river (Plate XV). For most of this distance the Wisconsin drift-plain on the east with its rounded hills and undrained marshes comes up to the very edge of Brooke creek valley. The east halves of section 36, Brooke township, and section 1, Elk township, just east of the valley, have a terminal moraine topography, and on the north line of section 13, Elk township, an exposure on the valley slope only eighty rods east of the creek shows Wisconsin till overlying sand. At a few places, as in the southwest part of Scott township, the ice may have stopped a short distance east of the creek on the valley slope, but even there the material washed down from the ice-margin modified the surface so that there is no typical Kansan drift topography on the east side of Brooke creek.

The exact course of the boundary in the angle between the Little Sioux and Brooke creek valleys is rather indefinite because of erosion. At the south line of section 24, Brooke township, the boundary draws away from Brooke creek and runs directly north through the centers of sections 24 and 13. Between this boundary and Brooke creek to the west the surface is much dissected into spurs projecting westward, which have a uniform level and are capped with a gravel deposit. In the southeast part of section 12 the boundary turns sharply to the east, parallel with the south bluff of the Little Sioux valley.

Along the Little Sioux Valley from Brooke Creek to Gillett Grove.—From the mouth of Brooke creek eastward and northward, the Wisconsin drift-boundary follows closely the southeast edge of the Little Sioux valley past Linn Grove and Sioux Rapids, to Gillett Grove in southeastern Clay county (Plate XV).

This is one of the most peculiar and interesting parts of the whole boundary. Extending in a southwesterly direction, the boundary touches the valley at Gillett Grove and then for about twenty-five miles follows the edge of the valley, passing, in that distance only nine miles to the south and fully twelve miles to the west. The ice pushed westward into the loop of the river in Herdland township, Clay county, and then westward along the south side of the valley past Sioux Rapids and Linn Grove to eastern Brooke township. It even pushed back northward into the loops at Sioux Rapids and in section 3, Barnes township. Making all possible allowances for the southward retreat of the valley-wall in the southward loops to the east and west of Sioux Rapids, it still seems evident that the direction of ice motion was really somewhat northward into these loops, especially in the case of the one in Barnes township. It would be interesting to have a record of the path of the ice which came out to the boundary in northern Barnes township, for at the margin in sections 10 and 3 it must have had a direction of motion nearly opposite to that which it had at the north line of the state.

This westward thrust carried the ice into the angle formed by the Brooke and Little Sioux valleys, where the boundary turns abruptly at almost a right angle. The force which caused this westward thrust of the ice seems to have been fully spent when northwestern Buena Vista county was reached, for here the boundary changes direction to east of south and holds this course southward through Buena Vista, Sac and Carroll counties.

What the course of the boundary would have been between Gillett Grove and Brooke township had there been no Little Sioux valley, can be only conjectured, but it probably would not have been very different. The boundary has a southwest direction where it strikes the Little Sioux at Gillett Grove and this general direction continues to section 16 of Herdland township. From here westward to Linn Grove its exact course was influenced by the valley. However, the course of this part of the Little Sioux valley was itself probably determined by the position of the ice-front, and had the force of the thrust westward not been largely spent, the river would have been crowded farther over into southern Clay county. Without the valley the ice-front probably would have gone on west across southwestern Herdland and southern Douglas townships.

This westward thrust of the Wisconsin ice seems still more peculiar in view of the fact that the southwest direction which must have prevailed over southeastern Clay and across Buena Vista counties was transverse to the drainage courses of that time, and almost directly up the slope of the great watershed, and that the northwesterly direction which was held at least locally was directly up the valleys. Certainly no favorable topographic configuration is to be found to explain this westward thrust of the Wisconsin ice.

The marginal portion of the Wisconsin drift-region in Buena Vista county and the southeast corner of Clay county is a slightly rolling glacial plain with scattered patches of slightly hummocky topography (Plate XV). These patches consist of single hummocks or kames, of irregular or roughly equidimensional patches, and of elongate areas. Most of the areas cover only a small part of a square mile and none more than a square mile. There appears to be no regular distribution of these patches. Some of them are near the margin, as in section 36, Brooke township, and section 1, Elk township, and in sections 27 and 21, Washington township. Some are several miles back from the boundary as in sections 22, 23 and 10, Washington township, in sections 35, 33 and 1, Scott township, and in the west parts of sections 18 and 19, Lee township. They are most numerous in Washington township north of Storm Lake, and thence isolated patches are present in Scott, Barnes, Lee and Herdland townships. Detailed study of this region probably would show that many of these isolated patches of terminal moraine could be aligned in belts which mark short periods of rest for the ice-margin.

The chief feature of the Wisconsin plain, however, is not the patches of hummocky topography but the large undulations, depressions and elevations, of the ground moraine type. The hills are large, some of them covering a quarter-section, and their slopes are gentle.

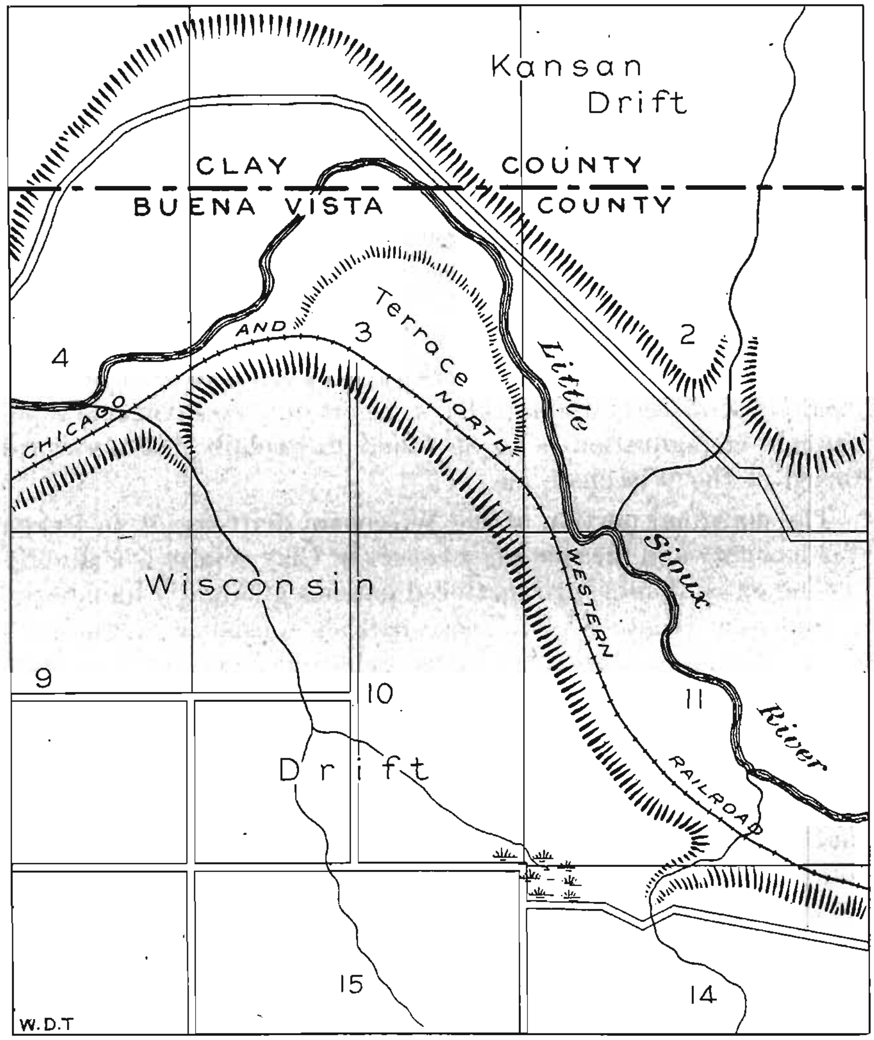


FIG. 29. Sketch map of a part of northern Barnes township, Buena Vista county, showing immature drainage on the Wisconsin drift. The swamp at the northwest corner of section 14 is only a quarter of a mile from the edge of the Little Sioux valley to the northeast, but the drainage goes northwest and travels two miles before it reaches the river.

A good illustration of the recency of the plain and of the independence of the relief features with respect to the drainage courses, is found at the northwest corner of section 14 of Barnes township (figure 29). Here is a swamp about ten acres in extent, on the upland and within one-fourth mile of the edge of the Little Sioux valley to the northeast. It drains, however, to the northwest and its waters reach the river only after a course of two miles.

East of the center line of Buena Vista county the region passes into a slightly rolling to flat glacial plain, and this continues eastward across western Pocahontas county. Shallow depressions occupied by marshes or shallow ponds once dotted this plain, but most of them have been drained by ditching or tiling and now form the richest of agricultural land.

Through sections 7 and 8 of Barnes township, south of Linn Grove, the boundary is about half a mile south of the Little Sioux valley, leaving a narrow strip of the older plain to the south of the valley as in sections 24 and 13 of Brooke township just to the west. Erosion has obscured the evidence in the northern part of section 9, Barnes township, but probably this area was covered by the Wisconsin ice and the margin came to the valley edge at the northwest corner of this section. The margin is the edge of the bluff eastward through Barnes township and the glacial topography extends northward through section 10 into the loop of the river valley in section 3. At Sioux Rapids there is another northward loop of the river and the ice pushed well out into this loop, at least to the north line of section 7, Lee township, and probably to the end of the spur of the upland. To the east the boundary is close to the river bluff through section 8, Lee township, but in the northwest quarter of section 9 it draws away from the bluff, extends northeast across section 4, and crosses the county line at the northwest corner of section 3.

In Herdland township of Clay county the boundary extends north along the west line of section 34 and meets the edge of the valley again in the southwest quarter of section 27. The southeast part of section 33 and the northwest part of section 4 to the south, between the boundary and the valley edge, have an even surface of the type found west of the river. The west parts of sections 27 and 22 are much dissected and the Wisconsin topography has been entirely destroyed, but the presence of Wisconsin drift shows that the ice here pushed up to the edge of the valley. At one place in the west part of section 27, where every trace of Wisconsin topography has been destroyed, a steep ravine slope showed fifteen feet of Wisconsin till above fifty feet of older till, and at several places in the west part of section 22, exposures of twenty feet of Wisconsin till were found. The Wisconsin drift-plain extends westward through section 16 into the loop of the river in western Herdland township, and to the edge of the valley northward through northern Herdland and southeastern Gillett Grove townships to the mouth of Elk creek.

In sections 27 and 22, Herdland township, most of the spurs between the valley-side ravines show narrow shoulder-like areas sixty-five to seventy feet above the river. These are remnants of a narrow bench which once existed along the side of the valley. Farther north the bench is less dissected and broadens out in the west part of section 16, to a width of half a mile, although it is not clearly separated from the plain to the east. Through northern Herdland and southeastern Gillett Grove townships it is narrower. Very little of this bench is level and in places it has a glacial topography. The inner boundary is commonly indefinite, so that the bench area grades into the glacial topography to the east. The surface material is in most places a gravel or bowlder deposit, but locally Wisconsin or older till appears beneath this. Bowlders are common especially on the crest of the front overlooking the river. When the ice had withdrawn slightly from its maximum extent and while there was yet obstructed drainage in the valley at the level of the bench area, gravel material was washed down from the ice-front to the east and spread out in the ponded waters of the valley. With the deeper cutting of the valley this leveled-up area was largely destroyed, but a few benches remain.

The mapping of a boundary so peculiar as the one just traced from Brooke creek to Gillett Grove should be based upon very firm data and such is the character of the data with which we are dealing. They consist first of physiographic evidence and second of stratigraphic and lithologic evidence.

The Wisconsin drift-plain on the south and east of the valley has a distinctly glacial topography, the chief features of which are of the ground moraine type, but which include also small scattered patches of terminal moraine (Plate XV). This glacial topography, so distinctive of the Wisconsin drift-regions, continues up to the very edge of the Little Sioux valley and pushes out into the northward and westward curves of the valley.

On the north and west of the Big Sioux valley in Clay county the region is very different. An even plain extends up to the edge of the valley, where it breaks off abruptly to steep valley sides. Viewed from across the valley the altitude of this crest is remarkably uniform (figure 38, page 315). On the south where the glacial topography extends to the edge of the valley the crest is not so sharp as on the north and the valley slope passes more gradually into the rolling plain of the upland. In some places, as in Herdland township, the altitude of the crest of the northwest bluff, which comes within a quarter to half a mile of the river, is not reached on the southeast of the valley within a distance of three to four miles (figure 30). Back on the plain to the north the surface has only a slight relief, less than that of the Wisconsin drift-plain, but the features of this plain are broad valleys and rounded divides. Many of the slopes are very gentle, so that the surface appears almost flat, but there is some slope, and the drainage of the region is complete. Nearer the larger valleys, such as Willow creek, the relief is greater, and the slopes are steeper, but the features are of the same general type.

The evidence which determines the location of the Wisconsin boundary, however, is not simply physiographic, although this is thoroughly adequate for the conclusion that the Wisconsin ice pushed up to the Little Sioux valley from Gillett Grove to Linn Grove and occupied all the territory to the south and east, but did not at any place cross the Little Sioux valley. One cannot go

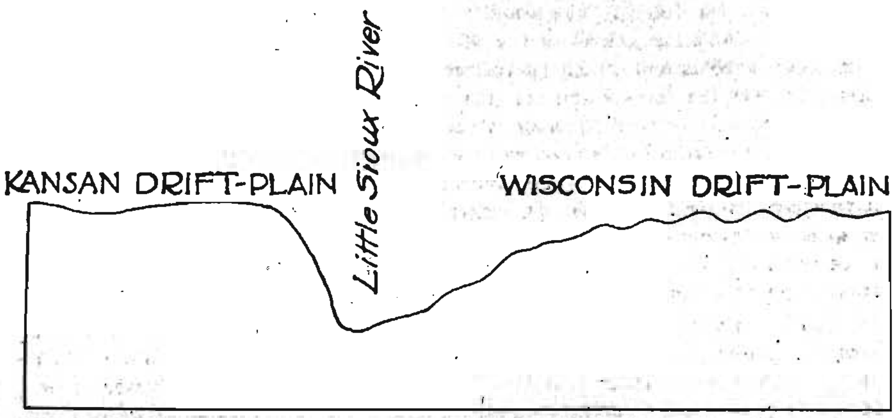


FIG. 30. Profile across the Little Sioux valley in Herdland township, Clay county. The even upland on the left is the Kansan drift-plain. The less abrupt slope on the right with undulating surface is the Wisconsin drift-plain.

far into the Wisconsin area before noting the pebbly, gritty soil and the presence of bowlders on the surface. On the Kansan area, on the other hand, bowlders are seldom seen and the surface is generally covered by a pebbleless, loesslike loam.

The drift into which the Little Sioux valley is cut from Gillett Grove to Linn Grove is Kansan. There are many exposures, natural and artificial, along the steep slopes of the valley and in the lower courses of the tributary ravines. On the north this till continues to the crest of the steep slopes, but in the upper portion of the south slopes of the valley and on the plain beyond one finds exposures of the Wisconsin till.

At the middle of the north line of section 9, Lee township, Buena Vista county, there are some pits in a sand and gravel horizon overlain by Wisconsin till, and underlain by the Kansan till. To the west down the slope toward the valley only the Kansan till appears, while eastward to the upland only Wisconsin till is seen.

East of Sioux Rapids the Chicago and North Western railway leaves the valley and passes eastward up a ravine to the upland. From Sioux Rapids eastward to the center of section 8, Lee township, only the Kansan till is exposed, but east of this, the railway is well up on the valley slope and Wisconsin drift forms the upper part of several of the exposures. A thin, ferruginous, stony horizon at the top of the older till, grayish blue silts, or a fresh sand horizon, separates the two tills in most cases, but locally the Wisconsin till rests directly upon the Kansan.

In the southwest part of Sioux Rapids where the Minneapolis and St. Louis railway crosses the wagon road by a high bridge, blue or brownish yellow till is exposed in the ravine bed, as also to the east along a gully and the railway cut, over a vertical thickness of about seventy feet. The till is typical Kansan and shows in its oxidation several stages intermediate between the blue clay and the yellow. Above the railway cut a grassed slope rises twenty feet to a gravel pit, which exposes about five feet of coarse gravel overlying an equal thickness of coarse sand. The sand becomes finer downward and there is said to be at least six feet of "quicksand" (probably fine sand) below the bottom of the pit. Above the gravel of the pit is a fresh light yellow till which contains a few pebbles and which pulverizes to a fine loesslike material with very little grit. On the face of the pit this till where dry is very hard and owing to horizontal and vertical jointing it breaks out in rectangular blocks. About four feet of this fresh till is exposed and then a grass-covered slope rises twenty feet to the top of the hill. This upper till is not typical Wisconsin, but from its position, its freshness, and its contrast with the Kansan down the slope, it must be the Wisconsin till. Across a ravine to the south is an abandoned pit in the same gravel stratum, which is overlain by the same light yellow till, and gravel appears at several other nearby places at the same altitude.

A short distance to the south, one hundred yards south of the northwest corner of section 18, Lee township, brownish yellow till forms the lower thirty feet of a roadside exposure, and blue till outcrops in a ravine bed lower down, about fifty yards to the northwest. At the top of the till is a six to twelve inch layer of rusty, sandy material, with some rotten bowlders. Then comes a blue-gray loesslike material, three and one-half feet thick, the upper part of which contains small gastropod shells that look like the ordinary loess fossils. The next horizon is more silty, as if deposited in water, and consists of several feet of bluish gray silts. Above these silts is several feet of sandy silt and fine sand which is banded brown and yellow and is followed by a zone of very fine silty sand six to eight feet thick. The total thickness of the loesslike silts and sands is fifteen to eighteen feet. The sand is overlain by a thin horizon of light yellow, sandy Wisconsin till, which farther up the slope grades into typical Wisconsin till.

At the center of the north line of section 13, Barnes township, the Kansan till rises ten feet above the railway and is overlain by a red iron-stained sand which passes into the soil at the top of the cut. A few rods south and ten to fifteen feet higher, on the south side of the wagon road, a cut exposes at the base six to eight feet of fresh sand overlain by fifteen to eighteen feet of Wisconsin till. Where it is dry this is very compact but it does not have the joints that characterize the Kansan. In one place this upper till contains iron tubules and has at the top a zone with many calcareous concretions.

Other Wisconsin drift exposures in the vicinity of Sioux Rapids may be seen at the top of the hill on the road leading south from Sioux Rapids through the southwest quarter of section 7, with the Kansan till exposed in the lower part of the slope to the north; eighty rods east of the southwest corner of section 7, with the older till on the slope to the west; and along the east side of the southeast quarter of section 7.

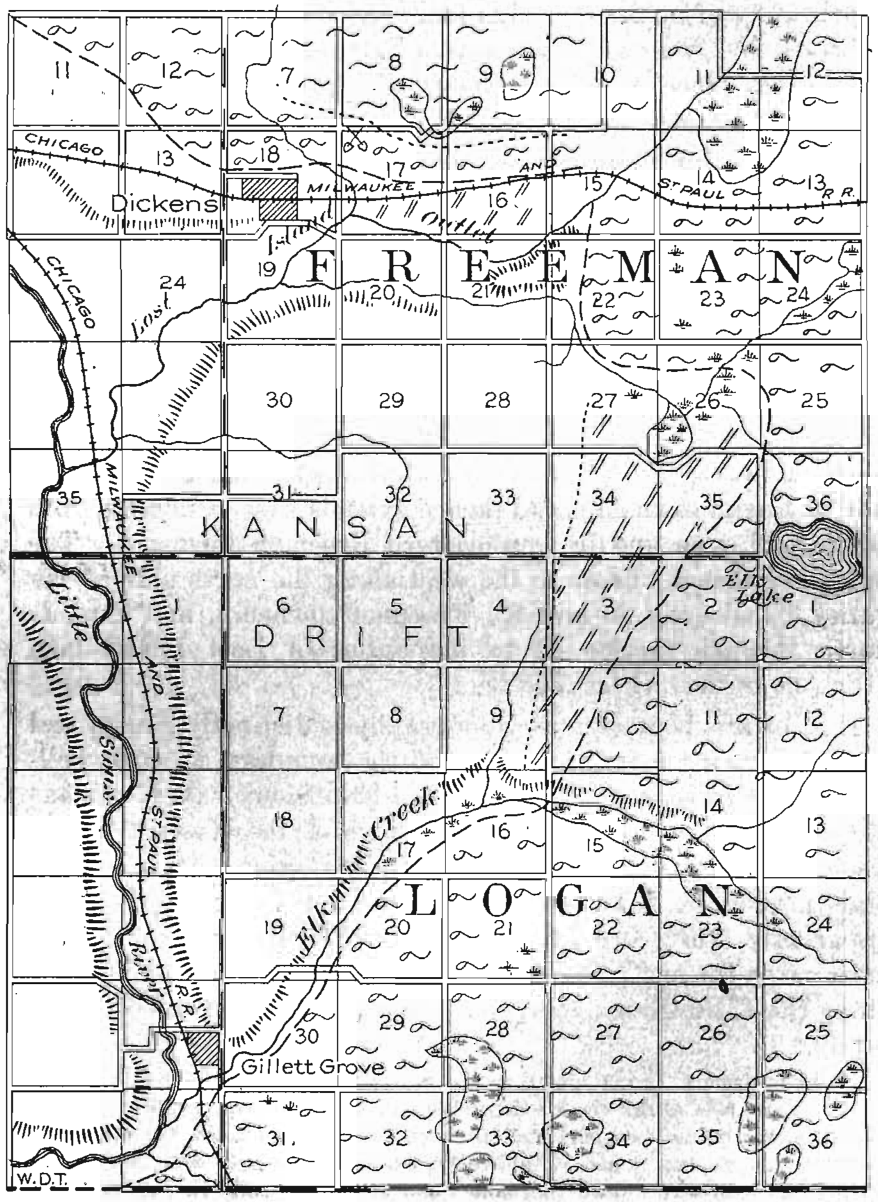
From Gillett Grove to the Dickens Outlet.—Near the township corner south of Gillett Grove, the relief and ruggedness of the Wisconsin topography increases, and in the southwest corner of Logan township the terminal moraine is prominent and extends eastward and northeastward across the township. This is the first large area of terminal moraine found along the Wisconsin boundary in all the course from Des Moines northward.

The southcentral part of Logan township is high, with a rugged topography of hummocky hills and ridges, inclosing depressions occupied by swamps and ponds. Farther eastward this high area gives place to elevated belts of terminal moraine with a north-south trend and separated by belts of lower altitude and less rugged topography. Farther south in Garfield township the moraine is weaker and is broken up into higher and lower belts of ground moraine with the same north-south trend. These extend into northeastern Buena Vista and northwestern Pocahontas counties with some patches of terminal moraine, and there the whole grades into a slightly rolling plain of ground moraine.

At the mouth of Elk creek south of Gillett Grove, the Wisconsin drift boundary leaves the Little Sioux valley and extends northeastward (Plate XVI). It follows Elk creek to the center line of Logan township, and thence extends east of north across northern Logan and in southeastern Freeman township. The boundary thence offsets to the west along the north side of the valley in sections 26 and 27, Freeman township, and extends north through section 22 to the outlet of Lost Island lake (Dickens outlet) (Plate XVI).

East of this boundary the topography is distinctly glacial and in part strongly morainic. West of the boundary a slighty rolling plain stretches westward to the Little Sioux valley. It has the gentle slopes and the broad valleys of the Kansan region west of the Little Sioux in Clay county. Some parts of this plain nearer the Wisconsin drift-border are especially flat, and apparently were affected by the outwash material from the moraine to the east. Near the valleys the relief is greater, and along the Little Sioux there is an area of well dissected topography.

Through western Logan township the edge of the Wisconsin drift-area lies along the east side of Elk creek valley (Plate XVI). The floor of this valley consists of marsh or meadow land and lies about seventy feet below the upland to the west. In sections 16 and 17 this valley floor is half a mile wide, but it narrows to the southwest, down the valley, and at the township line the flat has disappeared. In section 16 the direction of the valley changes to east by southeast, and it extends with a width of a quarter to half a mile, several miles into the area of the Wisconsin drift. The west slope of Elk creek valley along the Wisconsin boundary is steep and rises to a level crest that marks the elevation



Map of parts of Freeman and Logan townships of eastern Clay county, showing features discussed in the text. Curved lines with loops represent morainic Wisconsin drift. Curved lines represent Wisconsin drift. Parallel lines show area affected by outwash from the Wisconsin ice-sheet.

of the Kansan drift-plain to the west. Locally the slope is gullied and ravines head back into the plain. On the east the slope is longer and less steep, and passes more gradually into the glacial topography of the upland, which at a distance of a mile from the valley is somewhat higher than the upland on the west.

A slope rising thirty to forty feet above the region to the west marks the boundary through section 10, Logan township, but it is less prominent to the north in section 2, and is not present in southeast Freeman township; but the area to the east, along the county line, continues higher and slopes down to the west.

West of the boundary in northern Logan and southern Freeman townships there is a poorly developed outwash plain. At the south end where the boundary leaves Elk creek the outwash plain is less than half a mile wide, but it widens northward to one and one-half miles where it is terminated by the low area of sections 26 and 27, Freeman township (Plate XVI). Exposures within this area show only the finer materials such as sand and fine gravel, indicating that only relatively moderate floods came down over the region from the ice-front to the east. The amount of outwash material is probably slight, forming only a veneer, and in places it does not appear to have been sufficient to bury completely the slight relief of the Kansan drift-plain. The western border is an indefinite line where the gravel area grades into the slightly rolling plain to the west. Its course is along the east lines of sections 9 and 4 of Logan township, and through the west part of section 34, Freeman township (Plate XVI).

This is almost the first example of an outwash plain that is found in tracing the Wisconsin drift-margin northward from Des Moines. The boundary follows some drainage line most of the way and the debris was carried away by the streams. For this short distance between Elk creek and the northwestward flowing stream course of section 27, Freeman township, the ice-margin lay on an even plain and conditions were favorable for the accumulation of outwash deposits. Also the thickness of the ice and the length of time its margin remained along the boundary must have been much greater along this strong terminal moraine of eastern Clay county than farther south.

The continuation of the boundary traced northward through Logan and southeastern Freeman townships (page 267) would pass to the east of the low area of section 26, Freeman township, and extend northward through the central parts of sections 23 and 14; and this course would indeed leave all the strongly hummocky topography on the east. But there is to the west of this line an elevated area covering most of section 22 and extending into adjoining sections to the north, east and south, which has a topography consisting of large, rounded elevations of the ground moraine type, upon which appear some small hills of the terminal moraine type. It is separated from the terminal moraine to the east by a low area in the west part of section 23. It is higher than the drift-plain to the west down to which a slope leads in the northwest part of section 22, and must be included with the Wisconsin drift area. Almost surrounded by valleys, some of which are probably of pre-Wisconsin age, this elevation has been especially subjected to erosion, and many of its glacial features have been destroyed. A similar smaller elevation appears in the southwest part of section 14. The boundary mapped in central Freeman township therefore turns westward along the north border of the lowlands of sections 26 and 27 and extends north through the west part of section 22 to the outlet of Lost Island lake (Dickens outlet) near the center of section 15 (Plate XVI). It is a peculiar course, and would be more regular if the outer edge of the outwash plain were taken as the boundary through northern Logan and southern Freeman townships.

The Ruthven Moraine.—The area of pronounced terminal morainic topography which lies east of the Wisconsin boundary from Gillett Grove to central Freeman township continues northward along the county line and in western Palo Alto and Emmet counties, to the Minnesota state line. It is one of the prominent glacial features of northwestern Iowa, probably the most continuous of the morainic belts, and marks the western side of a strong moraine-forming ice-lobe which occupied the Des Moines drainage basin. The moraine has been named the Ruthven moraine from the town of Ruthven which stands on its crest near the west line of Palo Alto county. Its western boundary extends through eastcentral Freeman and Lake townships of Clay county, across the southeast corner of Dickinson county, through western Twelve Mile Lake and Estherville townships of Emmet county, and in southern Superior township in northeastern Dickinson county is terminated by the union of this moraine with another morainic area from the southwest (Plate XV).

The eastern boundary of the Ruthven moraine through northwestern Palo Alto county is at most points about two miles west of the Des Moines river valley, with an intervening belt of ground moraine (Plate XV). In southwestern Emmet county the terminal belt is close to the valley across Twelve Mile Lake township, but is again a mile back from it in southern Estherville township. North of Estherville, the boundary crosses the Des Moines valley and extends north through eastern Emmet township to the state line. From Ruthven north to the county line the moraine is eight to ten miles wide, but through Emmet county the average width is only four to six miles.

The topography of the Ruthven moraine is very rugged, with a relief of fifty to one hundred feet. The hummocks are steep-sided and many of them show bowldery or gravelly material on their summits. The depressions are likewise steep-sided and many of them contain small lakes or swamps which cannot be drained because of the depth of the depressions. Several lakes of some importance are included in the belt, as Elbow and Virgin lakes to the south of Ruthven, Lost Island and Trumbull lakes to the north, and Twelve Mile, Cheever, and Four Mile lakes in western Emmet county.

Southwestern Palo Alto county was not studied in detail by the writer. Professor Macbride mapped it on the Palo Alto county map[30a] as "Morainic Deposits," a division in which he placed all of those parts of Palo Alto and Emmet counties west of the Des Moines river valley. A general survey of the region, however, showed that southern Palo Alto county contains much that should not be classed with the Ruthven moraine. South of Ruthven, in Logan, Silver Lake and Great Oak townships, the moraine appears to separate into a number of belts which extend to the southwest, south and southeast. These are separated by belts of ground moraine, so that the whole forms a succession of terminal and ground moraine areas, or relatively elevated and depressed areas, which have a general trend from north to south. Farther south the terminal belts are weaker, in places mere isolated hummocky patches, and then these fail and the topography grades into the even glacial plain of eastern Buena Vista and of Pocahontas counties. The most prominent of these morainic areas is located along the county line and to the west in Logan and Garfield townships of Clay county (page 267), and south of the county corners in northeastern Buena Vista and northwestern Pocahontas counties. Other terminal moraine belts or areas, separated by ground moraine areas, were seen in Silver Lake, Great Oak, Rush Lake and Ellington townships of southern Palo Alto county. Detailed work in this region probably would show a system of diverging and disappearing moraines which mark the breaking-up of the Ruthven moraine.

A hundred miles to the east there is a similar prominent moraine which extends from north to south in western Worth, Cerro Gordo and Franklin counties. South of these counties this moraine likewise is progressively less prominent and it fails by many miles to attain the southward extent of the Des Moines lobe. These strong moraines of northern Iowa mark the loca-

[30a]Iowa Geol. Survey, Vol. XV, p. 254.

tion of the edges of the ice during much or all the time that the ice-front was advancing southward to Des Moines and retreating again to northern Iowa.

From the Dickens Outlet to the Okoboji Outlet.—The line which marks the extreme western edge of the Des Moines lobe turns westward north of the Dickens outlet in central Freeman township and extends west along the north border of the outlet to Dickens. The course is thence northwest across northeastern Sioux township, north through central Meadow township, and north by northwest through western Milford township of Dickinson county to the outlet of the Okoboji lakes (Okoboji outlet) northeast of the town of Milford (Plate XV and figure 31).

The features of this portion of the boundary are very different from those of southeastern Clay county, different also from those of the boundary through Buena Vista and Sac counties, and therefore the criteria upon which the separation is based are somewhat different from those used farther south. It is one of the most difficult parts of the boundary to trace, and calls for careful observation as well as familiarity with the significant but slight differences that exist.

The course along the north side of the Dickens outlet is marked by an inconspicuous terminal moraine, but northwest of Dickens the Wisconsin drift-region has only scattered patches of slightly hummocky topography. Part of the region to the west of the boundary in northern Clay county is more level than the Wisconsin drift-region, but glacial features are not present. West of the boundary in Milford township there is a narrow flat area which is in places marshy. It was a flat pre-Wisconsin surface, and probably was made more level by the outwash from the Wisconsin ice. It is widest west of the center of the township in sections 17 and 20 (figure 31), and extends southward to the county line as a narrower belt. On the west it merges gradually with the slightly rolling Kansan plain.

The Wisconsin margin reaches the south edge of the Dickens outlet in the southwest part of section 15, Freeman township. North of the outlet a low, ridgelike belt of terminal moraine about half a mile wide extends westward through the northern halves of sections 15, 16, 17 and 18 (Plate XVI). The south base of this ridge, which extends along the center lines of these sections, was mapped as the Wisconsin boundary. Between this boundary and the valley of

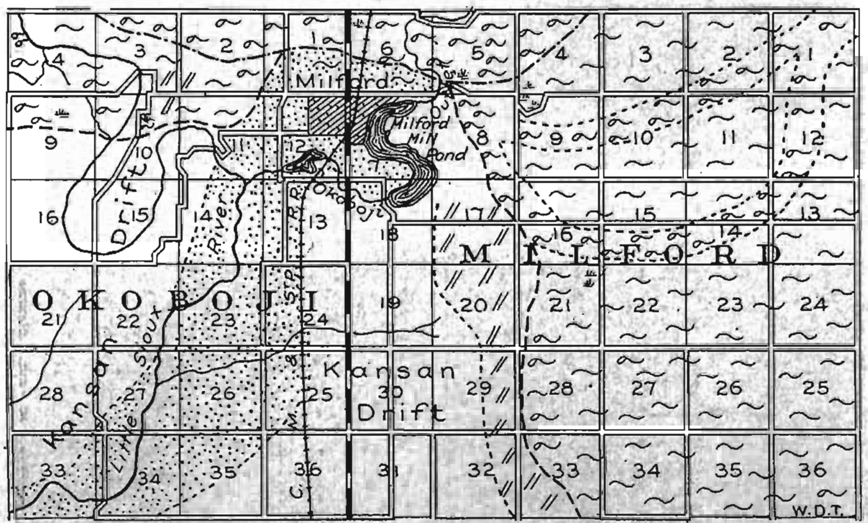


FIG. 31. Map of the region around Milford, Dickinson county, showing features discussed in the text. Curved lines with loops represent morainic Wisconsin drift. Curved lines represent Wisconsin drift. Parallel lines show area affected by outwash from the Wisconsin ice-sheet. The area shaded with dots is the Milford gravel flat.

the outlet, there is a narrow belt a quarter to half a mile wide, which has a slope toward the outlet, and is in part dissected and in part, as in the southeast quarter of section 16, is so level as to be marshy. This strip apparently was not covered by the Wisconsin ice, although it was modified by the outwash material. On the north, the morainic ridge has an indefinite border and grades into the ground moraine which, with a relief of ten to twenty feet and numerous swamp areas, covers the northern part of Freeman township (figure 32).

This moraine north of the outlet is quite insignificant in comparison with that of southeastern Clay county. It is, however, characteristically morainic, with hummocks of small relief, and at the northwest corner of section 17 there is a patch of definite terminal morainic topography with several gravel kames (Plate XVI). Just northwest of Dickens, in the northwest quarter of section 18, there is a good example of glacial topography of very slight relief. The surface is indeed quite level and yet one finds on close study those very significant little undrained depressions, here not deep enough to hold ponds but clearly marked by slightly marshy spots, and low mounds fortuitously placed with respect to the drainage courses. Bowlders were formerly rather abundant on the surface and several hundred are now piled along the fences in the fields just north of Dickens. On the south line of the southwest quarter of section 17, the roadside gutter on the west slope of the creek valley shows the older till overlain by three to four feet of Wisconsin till. The two tills are here very much alike, the chief difference being the more sandy nature of the Wisconsin which allows it to crumble and break with an uneven, granular surface, while the larger clay content of the older till makes it more plastic and causes it to break with a smooth surface.

FIG. 32. Wisconsin ground moraine of sections 8 and 9, Freeman township, Clay county. (Photo by Lees.)

At Dickens the drift-boundary turns northwest and extends along the southwest base of a low, broad ridge diagonally across the northeast quarter of section 13, the southwest quarter of section 12, the north half of section 11, and section 3, Sioux township, at a distance of one mile to one and one-half miles from the edge of the Little Sioux valley. To the northeast of this boundary there is an area of slightly rolling glacial topography with a few undrained depressions. To the southwest the region has a similar relief, but the distinctive glacial features are not found. Some parts just outside the boundary, especially in sections 11 and 10, are almost flat and probably were leveled up by outwash material.

In the north part of section 3, Sioux township, an interstream elevation begins and continuous northward into Meadow township, through the west half of section 34, and the east halves of sections 28 and 21 to the town of Langdon. In the west half of section 34 and the southeast quarter of section 28 the topography of this elevation is slightly hummocky. Farther north the hummocks are absent, but the topography is glacial with numerous ponds and marshes. The Wisconsin drift-boundary swings around the south end of this interstream elevation and extends northward along its west slope (Plate XV). To the west of the boundary the effect of the outwash is seen at several places in sections 28 and 21, where flat, marshy areas exist.

East of this boundary along the center line of Meadow township the topography is glacial and there exist other north-south interstream areas, like the one described above. One of these, with good terminal moraine topography, extends through the central part of section 27 and the east halves of sections 22, 15 and 10, and another through the east row of sections of the township. West of the boundary the surface is quite level but glacial features are absent. In the eastern part of the township gravel and stones are common at the surface, especially on the hills, but in the western part the roads are free from gritty material of any sort.

Northwest of the center of Meadow township there is a large marshy area. Glacial topography extends up to the east edge of the marsh, and within it, as in the northeast quarter of section 9, faint indications of glacial topography appear. The boundary, as mapped, swings to the east, through sections 15 and 10, along the east edge of the marsh, but the ice-edge probably formed, at least temporarily, a more direct line across the east parts of sections 16, 9 and 4. This marsh area lies just outside the Wisconsin drift-boundary and may have been leveled up slightly by outwash materials. Although it is marshy and almost flat, it is quite different from the enclosed glacial depressions in the Wisconsin drift.

Extending in an east-west direction through the north row of sections of Meadow township is a southward-facing front fifty to sixty feet high. It is a pre-Wisconsin feature that continues east through the northwest corner of Lake township and into southeastern Dickinson county. To the southwest this front lengthens into a long southward slope which crosses western Meadow and eastern Summit townships. The Wisconsin boundary strikes this front in the west part of section 3, and rising to the higher level to the north, leaves the county at the northeast corner of section 4. Section 3 is much dissected and most of its glacial features have been destroyed, but at the northwest corner a swamp appears and a glacial plain with bowlders on the surface lies just to the north over the county line.

In Milford township, Dickinson county, the boundary extends northwest diagonally across section 33, north along the west line of section 28, makes a slight reëntrant in the northwest quarter of section 21 and the southwest quarter of section 16, and thence extends northwest by north through the northeast quarter of section 17 and the central part of section 8 to the Okoboji outlet in the southeast quarter of section 6 (figure 31). The marginal topography of the Wisconsin drift of this township is in general, a slightly rolling ground moraine with a few patches of terminal moraine topography. In section 33 a low slope with a few small hummocks and granite bowlders marks the boundary, and in the northwest quarter of section 28 and the southwest quarter of section 21, near the margin, there are a few gravel kames. In the west part of section 16 and again in the east part of section 8 a small ridge area of terminal moraine approaches the boundary from the east and swings northward to unite with it (figure 31). The north part of section 8 is high and the topography is of the terminal moraine type.

The Terminal Moraine around Okoboji Lakes.—In the northwest corner of Milford township, the boundary abuts against an area which has a strong terminal morainic topography (figure 31). This area extends north to the Okoboji lakes, and continues, as a belt three to five miles wide, to the northeast and to the northwest. It is a belt of strong terminal moraine which loops the south end of the Okoboji lakes, and has in northwestern Milford township its most southern extension. To the northeast its outer edge crosses southeastern Center Grove and northwestern Richland townships, and in southern Superior township this morainic area spreads eastward so as to unite with the Ruthven moraine (Plate XV). A strong terminal moraine exists to the west and north of this boundary and covers most of the area to East Okoboji and Spirit lakes and to the Minnesota state line. Southeast of the boundary, southeastern Dickinson and northeastern Clay counties have in general a ground moraine topography, but with patches or belts of faint terminal moraine.

To the northwest, the outer edge of the strongly morainic area extends west across the north parts of sections 1, 2 and 3 of Okoboji township and then north along the Little Sioux valley through southern Lakeville township. From this boundary north and east to the lakes a strong terminal moraine topography is present as on the east side of the lakes (figure 33). In fact there exists in this area around the lakes probably the most pronounced morainic topography in the state. A belting of features somewhat parallel to the boundary noted above was observed in Diamond Lake, Spirit Lake, and Center Grove townships, and it appears that a lobe of ice (Okoboji lobe) occupied the site of the lakes and built this strong morainic topography around them. The solution of these interesting problems could not be entered into, but they will involve an exact mapping of this region around the lakes as well as a study of the district just to the north in Minnesota.

Great floods of water, from the ice-edge which built this strong moraine, flowed southward across sections 6 and 1 north of Milford, and later by the Okoboji outlet and by low courses leading southward from Brown and Emerson bays at the south end of West Okoboji lake. These waters built up the great gravel flat (Milford flat) which begins north of Milford and continues south and southwest to the Little Sioux river valley down which it con-

FIG. 33. Morainic topography at the north end of West Okoboji lake, Dickinson county. This district contains probably the most pronounced morainic topography in the state. (Photo by Ewers.)

tinues as a great gravel terrace across the southern part of the county and south to Spencer. The extent of this flat near Milford is shown in figure 31, and a view of the terrace which forms a distinct bench, high above the river but below the level of the upland, is given in figure 34. These gravels have been extensively worked just southwest of Milford for railway ballast.

The area of this aggraded flat, from its head north of Milford south to the county line, was at the time of its formation about eleven square miles. The thickness of the gravel varied greatly, but averaged about twenty feet, which over the area given above, would make a bulk of more than six billion cubic feet (one-twenty-fourth of a cubic mile). Southward in Clay county there is an area of more than fifty square miles over which the gravel had an average thickness of probably ten feet, making about fourteen billion cubic feet more. The total was about twenty billion cubic feet or about one-seventh of a cubic mile, and the major part of it entered the Little Sioux valley from the Okoboji outlet. This gives some idea of the great quantity of water and debris which was discharged at this place.

FIG. 34. The Little Sioux valley, looking west in the northwest quarter of section 13, Okoboji township, Dickinson county. The view is from the edge of the Milford terrace and shows the terrace on the west side of the river forming a distinct bench seventy feet above the river and twenty-five to thirty feet below the upland. (Macbride, Iowa Geological Survey, volume X, p. 199.)

From the Okoboji Outlet to the Ocheyedan River.—West of the Okoboji outlet the boundary of the Wisconsin drift extends westward across the north parts of Okoboji and Westport townships and along the south line of Allison township of Osceola county to the Ocheyedan river (Plate XV). In northwestern Okoboji township there is terminal moraine topography just north of the boundary, but farther west there is a belt a mile to two miles wide south of the terminal moraine belt which shows faint glacial characters. This is included in the Wisconsin drift. In Allison township, the marginal part of the Wisconsin drift is rougher than through western Dickinson county and in places there is a ridge just inside the boundary. In southeastern Ocheyedan township the edge of the Ocheyedan river flat is the boundary for several miles. For this distance the ice-sheet pushed down to the valley but did not close it. The ice pushed farther southward along the Ocheyedan valley than it would had there been no valley, so that where the ice-margin drew away from the valley on the east it had a course north of east for one and one-half miles until it reached the upland and there took the direction, a little south of east, which it held eastward to Little Sioux river.

Along the Wisconsin boundary from Little Sioux river to the Ocheyedan there is very little outwash material, although the ice-margin lay for most of this distance on a slightly rolling plain, under favorable conditions for the accumulation of debris. In western Okoboji and eastern Westport townships the area just south of the boundary for about a mile is almost flat, and similar smaller patches appear farther west in Allison township. These areas are aggraded only sufficiently to fill the shallow valleys that existed previously. Elsewhere in most places along the boundary a low slope continues southward a short distance and the surface shows the effect of outwash to the first small valley that leads either east or west to the southward flowing creeks. The way in which the outwash features terminate near the heads of even the smallest of these valleys shows that the quantity of water flowing from the ice-front at any one point was relatively small.

Where Stony creek leaves the Wisconsin boundary in northwestern Westport township its valley flat is more than a mile wide, but within two miles it narrows to about half a mile. Gravel underlies the flat, but its thickness is probably slight for the creek occupies one of the broad shallow valleys of the Kansan plain, and part of the gravel of the valley may be of pre-Wisconsin age. The Ocheyedan river valley flat in southwestern Osceola county is a mile to a mile and a half wide and is underlain with gravel and siltlike clay. Most of the flat is bottom land which is high enough to be cultivated and which slopes toward the river without terrace front.

The region to the south of the Wisconsin boundary in southwestern Dickinson and southeastern Osceola counties is slightly rolling, with some areas that are almost flat. The more level areas, aside from those leveled by outwash along the Wisconsin margin, are situated midway between the chief drainage lines and have a relief of only ten to fifteen feet. The relief is greater nearer to the larger creeks. The slopes of this region are long and gentle, and many parts that appear to be almost flat are found, on closer study, to have a slight slope toward some shallow drainage channel. There are no ponds like those in the Wisconsin drift area to the north, and no waste land in undrained depressions; but along some of the shallow drainage courses the surface is so level that slough grass meadows are formed. This is a surface distinctly different from that to the north and nowhere shows the distinctive features of glacial topography. The surface soil is a pebbleless loam which passes downward into leached loess. The soil and loess have a combined thickness of two to three feet. In the more level parts there are few exposures of the till, but in the more broken portions along the large valleys many exposures of the buff to brownish yellow till may be found.

From the Okoboji outlet westward to the center line of Okoboji township the location of the boundary is indefinite. The strong terminal moraine area extends southward to the centers of section 6, Milford township, and section 1, Okoboji township, and covers part of the north halves of sections 2 and 3 (figure 31). South of the center lines of sections 6 and 1 there is a narrow belt, thirty to forty rods wide, that has in part glacial features and in part features of the outwash area to the south. It is a sort of transition belt that apparently was covered by the Wisconsin ice, and later was modified by outwash material. In the east part of section 2 this belt is wider and shows several isolated glacial hills twenty to forty rods south of the center line of the section. In the west part of section 2 it is narrow again and so continues into section 3 just north of the center line. The southwest quarter of section 2, the southeast quarter of section 3 and most of the northeast quarter of section 10 have a slightly rolling or flat surface that also was modified by outwash. The north half of section 11 is a slightly elevated broad ridge without distinct glacial features, but bowlders were seen piled along the fences and lying in the fields.

Just north of the center of section 10, south of the farm buildings of Frank Hunt, there are a small pond and two small mounds. They are located on the crest of the spur of upland that projects southward into the loop of the Little Sioux and are not fifty yards from the valley slope either west or east (figure 31). Other small relief features in the field south of the pond have a glacial aspect, and west of the river positive glacial features continue as far south as this point. We therefore conclude that the Wisconsin ice covered the questionable areas described above, as far south as the center of section 10, and that east of here, the margin probably lay along the north edge of the Little Sioux valley as far as the center of section 11. From here the boundary extends north and east along the edge of the Milford gravel plain to the Okoboji outlet in section 6 of Milford township (figure 31).

West of the Little Sioux river a terminal moraine area, with swamps and gravelly kames, covers the north half of section 9. Bowlders appear at the surface, the soil is gravelly, and Wisconsin drift is exposed in several of the roadcuts on the north line of the section. This morainic area extends northwestward over the southwest quarter of section 4, the north part of section 8, and sections 5 and 6 of Okoboji township, and sections 32 and 31 of Lakeville township. Near the township corner the area divides. One branch extends northwest across the northeast quarter of section 36 and the south part of section 25 and dies out beyond the central part of section 26 of Excelsior township, and the other branch extends westward along the south line of Excelsior township. The latter belt is three-fourths to one mile wide and forms a low ridgelike area of moderately rolling topography with many slightly hummocky areas and undrained depressions containing swamps. The crest lies along, or just north of the township line, and the south border, which generally is an indefinite line, lies a quarter of a mile to half a mile to the south. The north border, likewise indefinite, lies about half a mile north of the township line, and north of this is a region of moderately rolling ground moraine with a relief of thirty to fifty feet.

West of the Little Sioux valley the Wisconsin boundary is formed by the south edge of the terminal area across the central parts of sections 9 and 8, Okoboji township. In section 9 a southward facing slope twenty to thirty feet high extends down to the plain to the south. At the west line of section 8, the edge of the terminal moraine belt extends northwestward, but the Wisconsin drift-boundary, that is the southern boundary of the area having glacial topography, turns south of west and continues across the central part of section 7 (Plate XV). In Westport township the boundary takes a course a little north of west through the southcentral part of section 12, the northcentral part of section 11, the north part of section 10 and along the north lines of sections 9 and 8 to the edge of the flat of Stony creek, which it follows across the southwest quarter of section 5 and the central part of section 6 to the county line. An area in the south parts of sections 5 and 4, of a rather questionable nature, is here included in the Wisconsin drift area. In section 7 of Okoboji township and two to three miles to the west in Westport township the boundary is marked by a low southward facing front which gives it a rather definite location. West of the center of the latter township the boundary is not definite.

Between the boundary and the belt of terminal moraine topography along the township line there is an area of glacial topography of the ground moraine type or with only occasional isolated hummocks. In part, it merges gradually into the terminal moraine topography to the north, and in part, it is definitely separated by a low southward facing front or a distinct change in the topography. On the east line of Westport township this belt has a width of more than a mile. It narrows towards the west and terminates in section 5.

In the southwest corner of Excelsior township there are a number of large swampy areas, with associated hummocky topography, which occupy depressions thirty to forty feet below the general level of the region. They occur along the outlet of Stony lake in sections 32 and 29, cover most of section 31, extend southward over the township line into the northwest quarter of section 6 of Westport township, and westward across the county line to include the east half of section 36 of Allison township.

The Wisconsin boundary crosses the east line of Osceola county about half a mile south of the northeast corner of Harrison township and continues its direction of north of west to Ocheyedan river. It extends along the north side of a creek valley through sections 1 and 2 of Harrison township, and thence passes through the south part of section 34 and the central part of section 33, Allison township. Section 32 is considerably eroded and the features are not clear, but the north part appears to be glacial, and the north part of section 31 has a slightly hummocky topography. The boundary is therefore mapped as changing its direction at the northwest corner of section 33 to extend south of west through the north part of section 32 to the edge of the Ocheyedan flat near the center of section 31 (Plate XV). This change of direction to south of west is due to the influence of the Ocheyedan valley upon the ice-margin.

The marginal part of the Wisconsin drift-area through southern Allison township is more rugged than through western Dickinson county. A ridge lies just inside the boundary in section 35, and in general the marginal portion slopes southward toward the boundary. The topography is moderately rolling and is generally of the ground moraine type, with a relief of twenty to forty feet. Slightly hummocky patches appear along the margin in the southeast quarter of section 35, the northeast quarter of section 33, the north part of section 31, and in the north part of section 36 and the south part of section 25 of Ocheyedan township.

The south and west parts of Allison township and the country west to the Ocheyedan valley have a topography of considerable relief, in which the larger features are of the ground moraine type but many small patches of slightly hummocky terminal moraine are included. These latter appear particularly along the depression in which Chain lakes lie, in sections 14, 23 and 26, and in the north parts of sections 28 and 29. The creek in the west part of the township has a valley one and one-half to two miles wide, and in section 20 its bed is eighty to one hundred feet below the divide to the east. But even along this valley most of the relief is constructional or is due to pre-Wisconsin erosion. Kamelike hills appear in the south part of section 30 and in the north part of section 31 along the creek valley.

From the Ocheyedan River to the State Line.—In crossing the Ocheyedan river valley the Wisconsin boundary offsets about two miles to the north and then the course is west across south-central Ocheyedan township, northwest across the northeast part of East Holman township, and north through the west part of Wilson township to the Minnesota state line near the town of Bigelow (Plate XV). For most of this distance, a low ridge area, one-half to one mile wide and with a moderately rolling or slightly hummocky topography, lies along the margin with the base of the outer slope forming the Wisconsin drift-boundary. The ridge itself is not very prominent, but when its significance is appreciated its course may be readily traced. Even where the ridge is wanting, the contrast of the topography to the northeast and to the southwest serves to locate the boundary.

Southwest of the Wisconsin boundary is the slightly rolling Kansan drift-plain. From the crest of the Wisconsin marginal ridge in southern Wilson and northern East Holman townships an excellent view may be had, showing the contrast between the Wisconsin and the Kansan drift topographies. To the east is the glacial area with its slightly hummocky hills and swampy depressions. The chief features of this region are elongated in a direction parallel to the Wisconsin drift-boundary. To the west, broad valleys with smooth slopes lead to the southwest. The courses of these valleys are direct, and one may look down them for miles. In the region to the east a pebbly, gravelly soil is found, and bowlders lie on the surface, while over the Kansan region the soil is pebbleless and no bowlders appear. The pebbleless soil is derived from a thin mantle of loess which overlies the Kansan drift.

Outwash material is absent from this portion of the boundary, just as was noted to be the case east of Ocheyedan river. At a few places, as in sections 21 and 20 of Ocheyedan township and in sections 29 and 20 of Wilson township, a gentle slope leads away from the boundary for a short distance, but commonly there is no evidence of outwash. For three miles in the east part of East Holman township and the west part of Ocheyedan township the ice-margin lay along the slope of the Little Ocheyedan valley, and the waters discharged directly into this valley. Similar conditions existed for two miles south of the state line where the ice-margin lay along the upper course of Otter creek. Neither of these valleys contains any very large gravel deposit. A long slope, cut by broad valleys, stretches to the southwest from the drift-boundary in northeastern East Holman township, and it seems that here the conditions should have been especially good for the accumulation of gravel in the valleys leading to the southwest and yet in these valleys and along the boundary there is no evidence of outwash material. Even the most insignificant valley was not obliterated and gentle slopes may lead directly toward the Wisconsin drift area to some small ravine that follows the drift boundary.

Great quantities of gravel exist to the southwest in the west part of the township, but on lithological and stratigraphical evidence these deposits, though close to the Wisconsin margin, are to be correlated with the gravels at Sheldon and elsewhere on the Kansan plain to the southwest, and are apparently not of Wisconsin age. The evidence as to the age of these extra-Wisconsin gravels will be considered at another place (pages 385 to 392), but even if the gravels at Sibley were the only deposits of this type, it would be hard to explain how they were derived from the ice-margin only three to four miles to the northeast, while the small valleys down which the material must have come, have no gravel deposits.

The general lack of outwash material along the Wisconsin boundary may mean that the marginal part of the ice was thin and that it melted slowly. The lack of outwash material would also indicate that the ice stood for a relatively short time at the line of maximum advance, an idea that is borne out by the slight development of terminal moraine along much of the boundary. The larger valleys however, such as those of Dickens outlet, Okoboji outlet, the Little Sioux, Stony creek and Ocheyedan river, carried great floods and extensive gravel deposits were put down. But even among these, that in the Okoboji outlet—Little Sioux course is the only great deposit. It seems, therefore, that the waters had collected into a few rather large streams either upon, within or beneath the ice before they reached the margin. These large streams generally came out in pre-Wisconsin valleys, and in some cases apparently had followed them for great distances beneath the ice.

If the margin is traced from the south, the first indication of the Wisconsin drift-area on the west side of the Ocheyedan valley is a spur, with rounded glacial hills and a bowldery surface, which projects slightly into the Ocheyedan flat in the southwest corner of section 23, Ocheyedan township. North of the center line of section 22, there is a low ridge fifteen to twenty feet above the region to the north and south. It extends south of west across the central part of section 21 and just south of the center of section 20. This ridge has a faint terminal moraine topography with several kamelike hills in section 21. The south base of the ridge, which extends forty to sixty rods north of the south lines of sections 22 and 21 and near the south line of section 20, is the Wisconsin drift-boundary. An exposure on the north line of section 28, less than half a mile south of the boundary showed beneath one and one-half feet of black soil a foot and a half of calcareous loess with concretions.

On the west line of section 20, the ridge is cut across by a creek valley from the north and in section 19 it is represented by a high rolling area between two valleys. This area continues northwest and broadens out into a high area of rolling glacial hills in sections 13 and 14 of East Holman township south of

Allendorf. The boundary is along the south base of this elevated area, along the north bank of the Little Ocheyedan valley through sections 19 and 24 and north of this valley through the south part of section 14.

The elevated area south of Allendorf is again broken in the west part of section 14 by the valley of the Little Ocheyedan, but it is continued in the northeast quarter of section 15 and the southeast quarter of section 10, covers most of section 10, and then assuming more ridgelike proportions, it extends west of north through the central part of section 4, and through the west part of section 33, the east part of section 29, and the south part of section 20 of Wilson township. This ridge is about half a mile wide from base to base, has a distinct slope in either direction from a rather narrow crest, and has in most places a slightly hummocky topography. The outer base of this ridge is the Wisconsin boundary. North of the center of section 20, Wilson township, the ridge spreads out eastward and unites with another elevated area, but the west slope retains its distinct features northward to the state line. The drift boundary is along the east slope of Otter creek valley through sections 17 and 18 and crosses the state line just west of the northeast corner of section 8 (Plate XV).

About sixty rods north of the southeast corner of section 22, Ocheyedan township, the road crosses the valley of a small stream that is flowing eastward along the Wisconsin drift-boundary. The road-cut in the south slope of the valley exposes brownish yellow Kansan till with concretions. The road-cut in the north slope exposes Wisconsin drift. It is in part a mass of pebbles and bowlders in a clay matrix, and in part a loose, yellow-gray, sandy till with many pebbles and bowlders. The topography to the north of this valley is typically glacial, that to the south is erosional, furnishing an excellent example of the contrast of the Wisconsin and Kansan drift topographies. Where the boundary crosses the township line on the west of section 19, it is following the Little Ocheyedan river valley. The north slope shows Wisconsin till and the south slope shows the older till. Wisconsin till appears in a road-cut a few rods east of the southwest corner of section 13, East Holman township, while just south of the same corner, the older till is exposed. About sixty rods north of the southeast corner of section 15 the road crosses a small valley which is parallel to the drift-boundary and here again Wisconsin till is present on the north slope of the valley and Kansan till is present on the south slope.

The Wisconsin Drift-Region in Northeastern Osceola County.—A mile to a mile and a half to the northeast of the marginal ridge noted above, and concentric with it, is another narrow ridge less well developed, but still traceable from Ocheyedan river to the state line. In Ocheyedan township it passes through the centers of sections 16 and 17 and the northeast quarter of section 18 and is separated from the ridge to the south by a low belt along the south line of these sections. In the southwest quarter of section 7, it unites with another ridge that extends across the southeast quarter of section 7 and the south part of section 8, and thence it continues northwest. It is crossed by the Chicago, Rock Island and Pacific railway at the east line of East Holman township, one mile east of Allendorf, and stretches across the southwest quarter of section 1 and the central part of section 2. A lower, less rough area at Allendorf and to the northwest, which is in part followed by creeks, separates it from the marginal ridge to the southwest. In Wilson township the inner ridge passes diagonally across section 34 and north through the east part of section 28 with a low, swampy belt to the west, and in section 21 merges with the marginal ridge to the west. The merged belt then continues northward beyond the state line. Its topography is a little rougher and its altitude a little greater than in the region just to the east.

Several other ridges or belts of hummocky topography concentric with these and extending for various distances are present to the northeast, in eastern Wilson and western Horton townships. There is a morainic belt or ridge along the east side of the Ocheyedan valley which extends across western Horton township, and terminates in an area of kames in sections 5 and 4 of northwestern Ocheyedan township. Other areas of hummocks or kames are present at a number of places in southern Horton and northern Ocheyedan townships. In the southwest quarter of section 12, Ocheyedan township, a large kame (Ocheyedan mound) rises distinctly above its surroundings and is a prominent feature, visible for many miles around (figure 35). It is elliptical in plan, as it is composed of two hills, it covers an area of almost forty acres and rises about 150 feet above the river two miles to the southwest. Two openings, one at the top and one on the north slope, show sand and gravel.

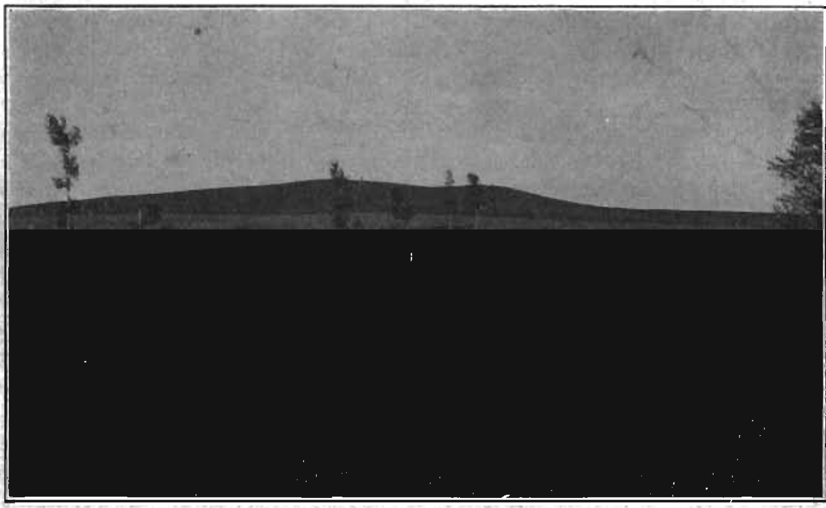


FIG. 35. Ocheyedan Mound, seen from the southwest. This hill is a Wisconsin gravel kame located in the southwest quarter of section 12, Ocheyedan township, Osceola county. It rises distinctly above its surroundings and is a prominent feature, visible for many miles around. (Macbride, Iowa Geological Survey, volume X, p. 195.)

Northern and eastern Horton township, and the southwest half of Fairview township have a ground moraine topography with a few patches of weak terminal moraine and this type continues southeastward over northern Allison township and into Excelsior township of Dickinson county.

Northeast of this ground moraine area is another more rugged terminal moraine area which covers northern Fairview, southwestern Silver Lake and northern Excelsior townships and should connect either eastward across northeastern Excelsior township to the moraine along and east of Little Sioux river in Lakeville township (page 276), or southeastward with the terminal moraine of southeastern Excelsior, southwestern Lakeville and northern Okoboji townships (page 280). Through Fairview township the southern boundary of this more rugged area is along a divide. To the south, the slope is very gentle across the slightly rolling glacial plain. The more rugged area to the north has a lower average altitude but the relief is greater, being thirty to fifty feet. Although it represents a terminal moraine belt it has not the distinctive terminal moraine topography found around the lakes of Dickinson county. Farther east in northern Excelsior township the boundary is less definite. A northeast boundary for this belt was not traced. It appears to pass gradually into a rolling ground moraine in northeastern Fairview and northern Silver Lake townships.

The Boundary North of the State Line.—The Wisconsin boundary was traced north of the state line into Minnesota a

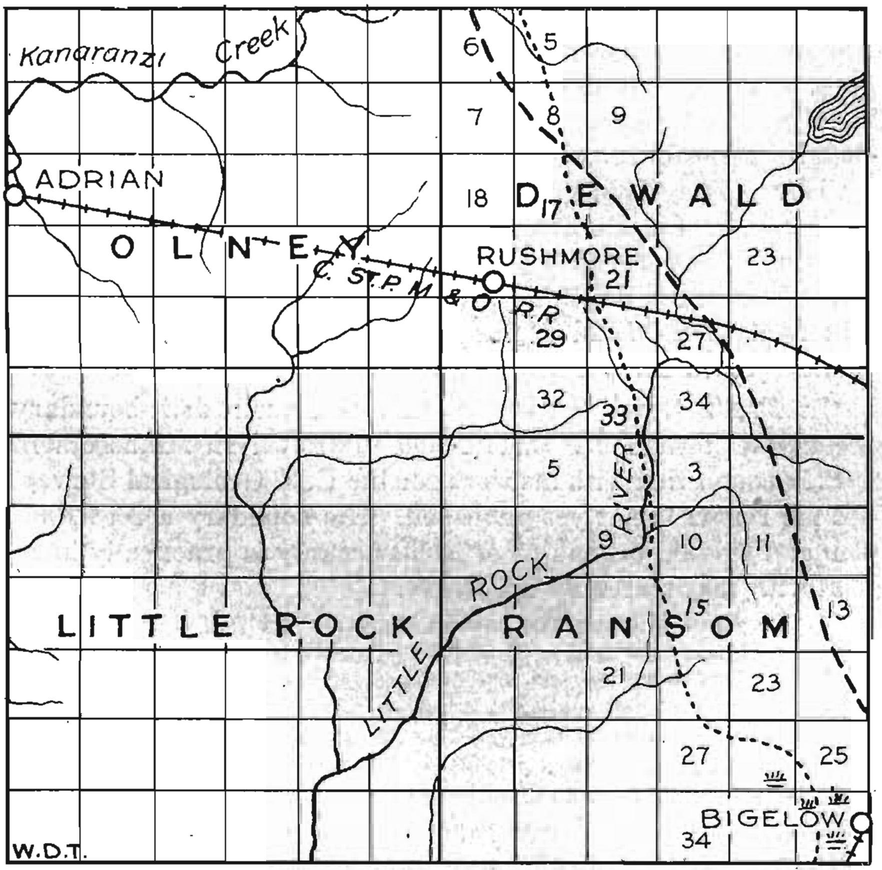


FIG. 36. Map of part of southern Nobles county, Minnesota. The heavy broken line shows the west boundary of the "Terminal Moraine" as mapped by Upham in The Geological and Natural History Survey of Minnesota, volume 1, Plate 21. The dotted line shows the course of the Wisconsin drift boundary as mapped by the writer.

distance of ten to twelve miles, across Ransom and Dewald townships of Nobles county (figure 36), and in this distance it continues in the general direction west of north.

In a report on Nobles county,[31] Warren Upham mapped a belt of terminal moraine running west of north across the county. The outer (west) boundary of this moraine is shown by the heavy broken line in figure 36. In Ransom township it is about two miles farther east than the Wisconsin drift-boundary as traced by the writer, but farther north in central Dewald township it intersects the Wisconsin boundary, and in northwest Dewald township is west of the Wisconsin drift boundary.

Farther northwest the Wisconsin boundary is probably approximately the outer edge of the Altamont moraine, at the crest of the Coteau des Prairies, as mapped by Upham and N. H. Winchell, through northern Nobles, western Murray, northeastern Pipestone and southwestern Lincoln counties (Plate XVII).[32] The Coteau des Prairies rises northward until in southwestern Lincoln county it is 300 to 500 feet above the plain to the west and 200 to 300 feet above the plain to the east. In South Dakota the boundary passes north by northwest through Altamont to the head of the Coteau in southwestern Roberts county (Plate XVII).[33]

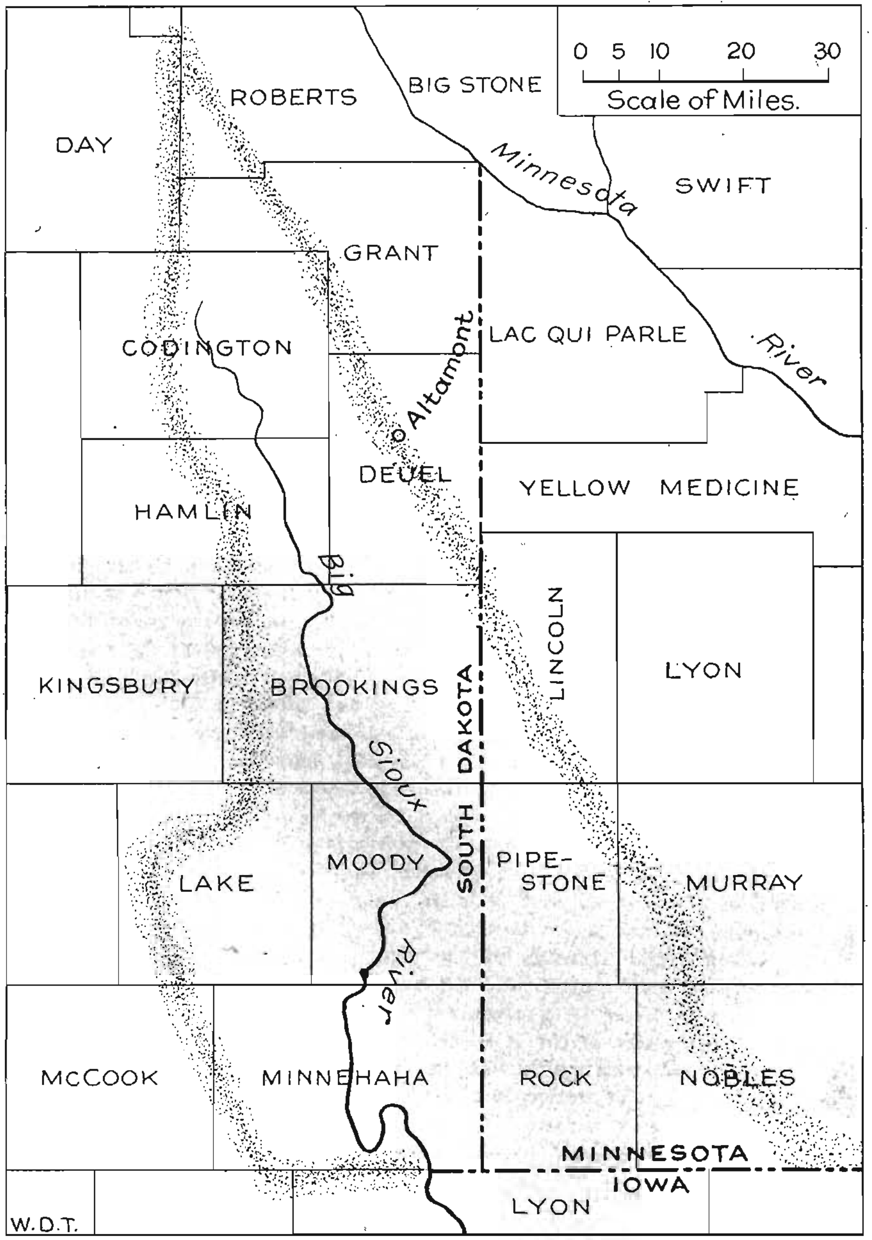
Mr. Frank Leverett retraced this Wisconsin drift-boundary through eastern South Dakota and southwestern Minnesota in 1912 in connection with his work for the U. S. Geological Survey, but his report is not yet published. His boundary across Ransom and Dewald townships of Nobles county is practically identical with that traced by the writer.

The Wisconsin drift-boundary crosses the state line half a mile west of Bigelow, Minnesota, in section 36 of Ransom township, Nobles county (figure 36). It extends along the east and northeast borders of a low marshy area that covers the west half of section 36, section 35, and the south half of section 26, and from the northwest corner of this marshy area in the northeast quarter of section 27, the boundary extends west of north through the central part of section 22, and diagonally across the west half of section 15. In the south-

[31] Upham, Warren, Geol. and Nat. History Survey of Minnesota, Vol. I, Pl. 21. 1884.

[32] Geol. and Nat. History Survey of Minnesota, Vol. I, Pls. 21, 24 and 27, 1884.

[33] Todd, J. E., The Moraines of the Missouri Coteau: U. S. Geol. Survey Bull. 144, Pl. 1, 1896.



Map of southwestern Minnesota and eastern South Dakota showing the course of the Altamont moraine. The part in Minnesota is after Upham and N. H. Winchell, that in South Dakota is after Todd.

east quarter of section 9 the boundary reaches the valley of Little Rock river and follows this valley north through the east part of sections 9 and 4 and into section 33 of Dewald township. Here Little Rock river heads northeastward into the Wisconsin drift-area and the boundary extends up a tributary from the north across the central part of section 33, and continues northward along the east side of a broad sag through the west part of section 28, along the west line of section 21 and through the east part of section 17. As it is seen from the south line of section 8, the boundary continues northward down a small valley across the central part of section 8 and the west part of section 5.

For most of this distance through Ransom and Dewald townships, a ridge-like area of Wisconsin drift lies just inside the boundary, and east of this at a distance of a mile to a mile and a half from the boundary, a more or less connected low area parallels the ridge. Small creeks flows north or south in this low area, and then break out through the ridge to the west. The headwaters of both Kanaranzi creek and Little Rock river in Dewald township have valleys of this type. The Wisconsin drift topography of the eastcentral part of Ransom township near the boundary is characteristically glacial but not terminal moraine; but in the north part of the township an area of rough terminal moraine begins and continues northward into Dewald township. A similar area extends eastward into Worthington and Bigelow townships.

Along most of the distance across these two townships a drainage channel parallels the drift-boundary. For two miles north of the state line it is the lowland area that drains southward into Otter creek. Thence for two miles, through sections 22 and 15, there is no valley along the boundary but at the southwest corner of section 9 the boundary touches the valley of Little Rock river and from here northward as far as the boundary was traced, a drainage line lies just to the west. Small deposits of gravel and sand were seen at a number of places along the boundary but there are no great deposits.

The most typical Wisconsin till of this area north of the state line is loose, sandy clay with many pebbles and occasional pockets of sand and gravel. At some places it is more compact but will pulverize to a mealy clay. The older till is plastic brownish yellow clay. West of the Wisconsin boundary the usual topography of the Kansan drift-plain is found. It is moderately rolling in western Ransom township, but north of Rushmore in Dewald township it is only slightly rolling. The drainage of the region is to the southwest, normal to the Wisconsin drift margin and the great watershed, to Rock river. The opposite slopes of Little Rock river valley in section 9 of Ransom township present a good contrast of the Wisconsin and Kansan drift topographies. The east slope is uneven, with glacial hills, and rises to the uneven crest line of the ridge in the east part of section 10. The west slope rises steeply and abruptly to an even crest line.

Summary.—As shown in plate XV the Wisconsin drift-boundary within our region makes some peculiar bends and angles. The direction and alignment of the boundary south of Linn Grove and north of the bend east of Sibley are the same, but between these points there is a great reëntrant of the boundary reaching twenty miles to the east. Within this reëntrant the boundary makes two abrupt bends, east of Dickens and east of Milford, and along the south side of this reëntrant the boundary follows all the bends of the Little Sioux valley. A proper interpretation of the entire course can be expected only after a thorough study of the Des Moines lobe, not only in Iowa, but also in southern Minnesota. It seems probable that the boundary is made up of parts of the margins of several lobes which were contemporaneous or followed each other closely, and that the several abrupt turns are at the angles where these lobes joined each other.

North of where it enters Iowa the boundary extends for a great distance along the side of a lobe in a direction east of south, but ten miles south of the state line it turns east rather abruptly and extends east across the front of the lobe through eastern Osceola and western Dickinson counties. An offset of two miles where it crosses the Ocheyedan valley, and a reëntrant around the head of the Milford flat are readily explained. The edge of this lobe probably ran east or northeast from Milford. The probability of a lobe of ice occupying the site of the Okoboji lakes was noted on page 276.

The change in direction of the boundary to a course almost due south, just east of Milford, seems to be due to the intersection of the edge of the lobe which has just been described with the west edge of another, minor lobe. The edge of this lobe forms the boundary for twelve to fifteen miles southward, where it changes direction and extends eastward across the front of the lobe past Dickens.

East of Dickens, in central Freeman township, this eastward course is again crossed by the west edge of the great Des Moines lobe, which is marked by the strong terminal moraine (Ruthven moraine) along the east lines of Dickinson and Clay counties. From a point east of Dickens, the west edge of the Des Moines ice lobe extended southwestward across southeastern Clay and northern Buena Vista counties and for most of the distance from Gillett Grove to Linn Grove, the ice edge lay along the course of the Little Sioux valley. From western Buena Vista county, the west edge of the lobe had a course east of south across Buena Vista and Sac counties, and southeast across Carroll and Guthrie counties.

The course of the Wisconsin boundary from the point where it turns northward in East Holman township of Osceola county to the head of the Coteau des Prairies in southwestern Roberts county, South Dakota, a distance of 160 miles, is very uniform and marks the western limit of a single ice-lobe, in contrast with the several minor lobes which apparently formed the boundary in northwestern Iowa.

COMPARISON OF THE COURSE AS RETRACED, WITH EARLIER TRACING.

The work of the writer in Sac and Buena Vista counties, in so far as the location of the Wisconsin drift-boundary is concerned, essentially verified the work of Professor Macbride, as the location of the boundary was changed only locally. The greatest changes were in showing that the Wisconsin ice pushed up to the edge of Brooke creek valley in Elk and Brooke townships of Buena Vista county, and farther northwest into the angle between Brooke creek and the Little Sioux river valleys, and in shifting the boundary two miles farther west on the south side of Wall lake outlet.

The course in eastern Clay county is also essentially that given by Professor Macbride in his discussion of the "Wisconsin Margin," in the report on Cherokee and Buena Vista counties, which is, however, very different from the earlier interpretation given in the report on Clay county. The map published by Professor Macbride in the report on Cherokee and Buena Vista counties is reproduced as figure 28 on page 249. The scale of this revised map is so small that exact comparison of borders is not advisable, but the boundary between the "Knobby Drift" and the "Wisconsin Drift Plain" divisions of the Clay county map in Logan and Freeman townships must have been the line used later as the margin of the Wisconsin area, and this boundary is incorrect in several places. Elk creek valley should form the boundary of the "Knobby Drift" area of Logan township, and an area of eight to ten square miles in northern Logan and southern Freeman townships, that is either flat outwash plain or slightly rolling Kansan drift-plain, was included in the "Knobby Drift" division.

North of Dickens the boundary as traced by the writer diverges from that of Professor Macbride, and there is no further correspondence of the two northward to the state line. In his discussion of the Wisconsin margin noted above, Macbride carries the boundary west from Dickens past Spencer to Everly, and thence up the northeast bank of the Ocheyedan to the state line (figure 28). No discussion of this course is given by Professor Macbride and since it does not agree in any way with his earlier mapping in these counties, one is left to infer or search out in the field the evidence upon which this interpretation may have been based. The north part of Clay county and southwestern Dickinson are quite level, and probably were considered Wisconsin for this reason. In fact the northern part of Clay county north of Spencer shows flat marshy areas, but these are not of the type found in the enclosed basins of the Wisconsin drift-region. Belts of low rounded hills lie north of the Spencer flat in Sioux township, north of the Ocheyedan plain in Riverton and Lone Tree townships, and at the edge of the Ocheyedan valley in the southeast corner of Osceola county, along the course of Macbride's revised moraine, and this probably constitutes part of the evidence for the location of the moraine. The hills of these belts are, however, sand hills and are not morainic (page 330).

This retracing of the Wisconsin drift boundary left outside the Wisconsin area the whole of the level region of Clay, O'Brien and Osceola counties which had been called the extra-morainic Wisconsin. Although it fixed a definite Wisconsin boundary, it left unsolved the problems of the extra-morainic area, except that in fixing the boundary, it made this area west of the boundary, pre-Wisconsin. This retracing also left outside the Wisconsin area the hills in Waterford township in northwestern Clay county, which contain much sand and gravel, and the gravelly kamelike hills of northeastern Lyon county. This extra-morainic region and its problems will be considered in Chapter III.

The Wisconsin Drift in the Region of Sioux Falls.

EARLIER WORK.

In 1883 Professor Chamberlin, in his paper on the Terminal Moraine of the Second Glacial Epoch,[34] traced the moraine on the east side of the Dakota lobe southward from the head of the Coteau des Prairies in northeastern South Dakota (figure 26) to a point in northwestern Lincoln county southwest of Sioux Falls. Then, attributing the determination to Professor Todd, he states that the moraine "bears eastward to the vicinity of the Big Sioux River, and thence follows the hilly tract bordering its west side southward into Union county." This brings the Wisconsin drift-region to the edge of the Big Sioux valley opposite Lyon county.

In 1896, Professor Todd, in bulletin 144 of the U. S. Geological Survey, mapped a belt of "Morainic Surface", which, from the Big Sioux valley opposite the Iowa state line, extends west along the Minehaha-Lincoln county line and thence northwest across the southwest corner of Minnehaha county. It is shown by the shaded area in figure 37. In bulletin 158 (1899), of the same series, Professor Todd showed the morainic belt as on the earlier map, and described (page 35) "a high massive ridge" as beginning on the west side of the Big Sioux, one mile north of the Iowa-Minnesota state line and extending west along the course shown in figure 37. This ridge was interpreted as the northeast boundary of the Dakota lobe of the Wisconsin drift-plain. The area to the northeast, including Sioux Falls and beyond, lies between the Dakota and Des Moines lobes. The maps of Professor Todd show also two patches of morainic surface northeast of Canton and a belt extending from a point south of Canton southwest through Beresford (figure 37).

In 1900 Professor Wilder studied the Geology of Lyon county, in the northwest corner of Iowa.[35] He accepted the mapping of the Dakota plain opposite Lyon county as Wisconsin drift, and further enlarged the area in two ways; first by showing a belt of Wisconsin drift and a patch of Altamont moraine in western Lyon county, and second by placing the boundary, on the Dakota

[34] U. S. Geol. Survey Third Ann. Report., pp. 394-395.
[35] Iowa Geol. Survey, Vol. X, pp. 137-141 and map, p. 118.

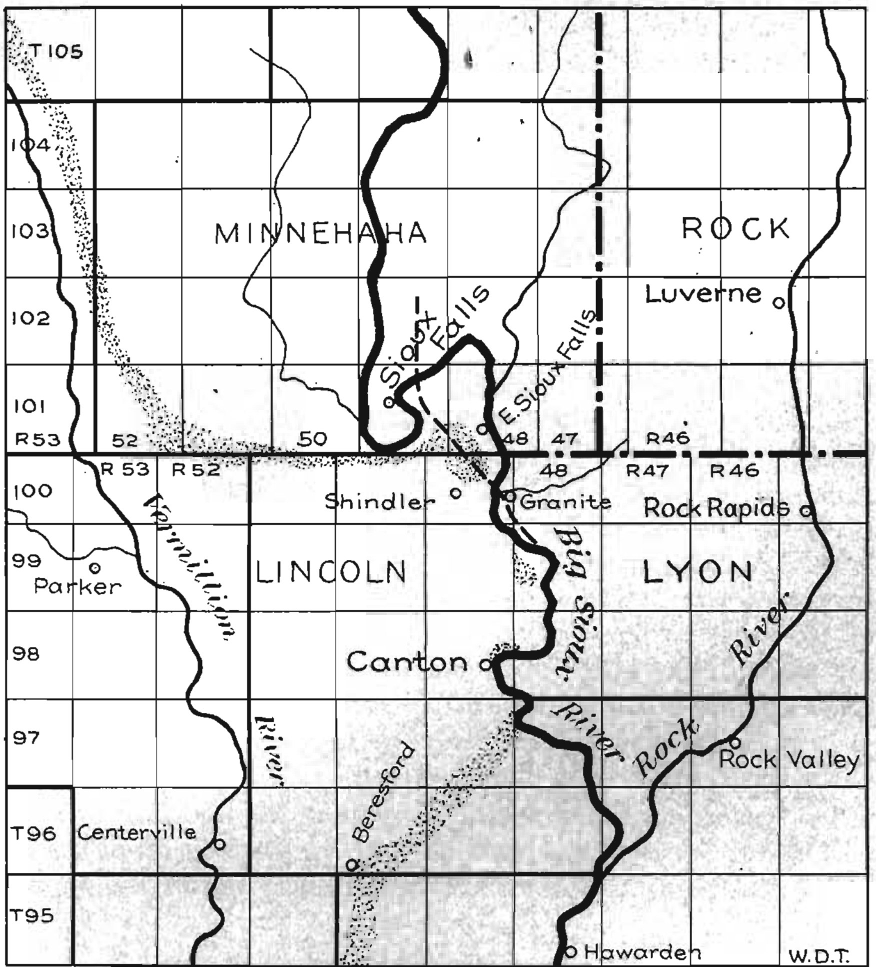


FIG. 37. Map showing a portion of eastern South Dakota and adjoining parts of Iowa and Minnesota. The shaded area shows the course of the Altamont Moraine as mapped by Todd in bulletins 144 and 158, U. S. Geological Survey. The broken line is the course of the Altamont Moraine as described by Wilder in the Lyon county report of the Iowa Geological Survey, volume X.

side, east of Sioux Falls. This so-called Wisconsin drift area of western Lyon county, as shown on the map of the surface deposits of the county, begins at the mouth of Blood Run, west of Granite, and continues south two miles as a belt about half a mile wide and thence three miles farther to the southeast as a narrow belt less than a quarter of a mile wide. At the north end of the belt, a circular area of Altamont moraine was mapped. Concerning the Wisconsin border on the Dakota side, Wilder says (page 141), "From the point where the moraine crosses the river, west of Granite, to Sioux Falls it is easily traced as a well defined, bowlder-strewn ridge. It passes east of Sioux Falls and crosses the river two miles northeast of the town. Thence for ten miles it was traced nearly due north." The course of this border located from the statement just quoted is shown by a heavy broken line in figure 37.

When the writer examined this Wisconsin drift area and Altamont moraine of western Lyon county, about half of the area mapped as Wisconsin was found to be on a terrace of the Big Sioux valley with nothing more suggestive of a moraine than Indian mounds, and the remainder is on a steep slope of a rugged upland in a topography that is a combination of eolian and erosional work. The hills in the northeast quarter of section 26, Sioux township, which were discussed by Wilder and were interpreted as morainic mounds, are Indian mounds. Most of them have been opened, and shells and fragments of bones lie on the slopes of many of them. The only features found along the front of the bluff which might suggest morainic hills are some shoulders well up toward the top. These have a common altitude and although from below they look like mounds, from above their character is plainly seen.

The conclusion of the writer was, therefore, that this area is not Wisconsin drift and that no part of the Wisconsin drift-plain of the Dakota lobe exists on the Iowa side of Big Sioux river.

Only a few weeks later Professor Shimek of the Iowa Geological Survey, working independently of the writer and upon other problems, examined this Wisconsin area of western Lyon county and reached the same conclusions concerning it. But Professor Shimek went much further in his restriction of the Wisconsin area, and among the conclusions of his paper, is the following:[36] "The plain extending from Shindlar to Canton, South Dakota, is Kansan and not Wisconsin". This is an area that was included by Chamberlin, Todd and Wilder in the Wisconsin drift-plain, and the writer in traveling across it by rail had seen what he thought to be conclusive evidence of Wisconsin

[36]Shimek, B., Bulletin of Geol. Society of America, Vol. 23, p. 154, 1912.

age. If this is not Wisconsin drift, it seemed as if serious inroads would have to be made upon the Wisconsin drift-plain of Dakota. It therefore seemed worth while to examine this Dakota plain opposite Lyon county to try to determine the identity of the Wisconsin drift-plain and then to locate more exactly its boundaries, for as was noted above, the statement of Professor Wilder concerning this boundary does not agree with the mapping of Professor Todd.

The results of this study on the Dakota side have already been published in another place,[37] but since the region concerned is so close to our area, and since the criteria upon which the identification of the Wisconsin drift-plain of Dakota is based are the same as those used for the identification of the Wisconsin drift-plain to the east in Osceola and Dickinson counties, it seems worth while to include here the treatment of this area.

CHARACTERS OF THE WISCONSIN DRIFT-PLAIN.

The western part of Lyon county, Iowa, is very rugged, with a submaturely dissected topography. The narrow divides stand at an altitude of 1400 to 1480 feet above sea level and below this there is a relief of 100 to 150 feet. The surface material is loess, and the drift exposures are of yellow Kansan clay. The eastern portion of Lincoln county, South Dakota, opposite Lyon county, is, however, a relatively level plain, sloping gently to the south and east. Near its eastern margin at the Big Sioux there are a few narrow valleys, but the dominating feature of the region is the relatively level plain. This plain has no loess covering. The high divides on the east side of the river, from the state line south to a point opposite Canton, have a uniform elevation of about 1460 feet above sea level. Opposite the state line the elevation of the Dakota plain is about 1400 feet, which is about 150 feet above the river and about 60 feet below the Iowa divides. But the elevation of the plain decreases southward more rapidly than the river falls, and north of Canton the edge of the plain overlooking the valley has an elevation of only 1320 to 1340 feet, which is only eighty to ninety feet above the river and more than a hundred feet below the divides of the

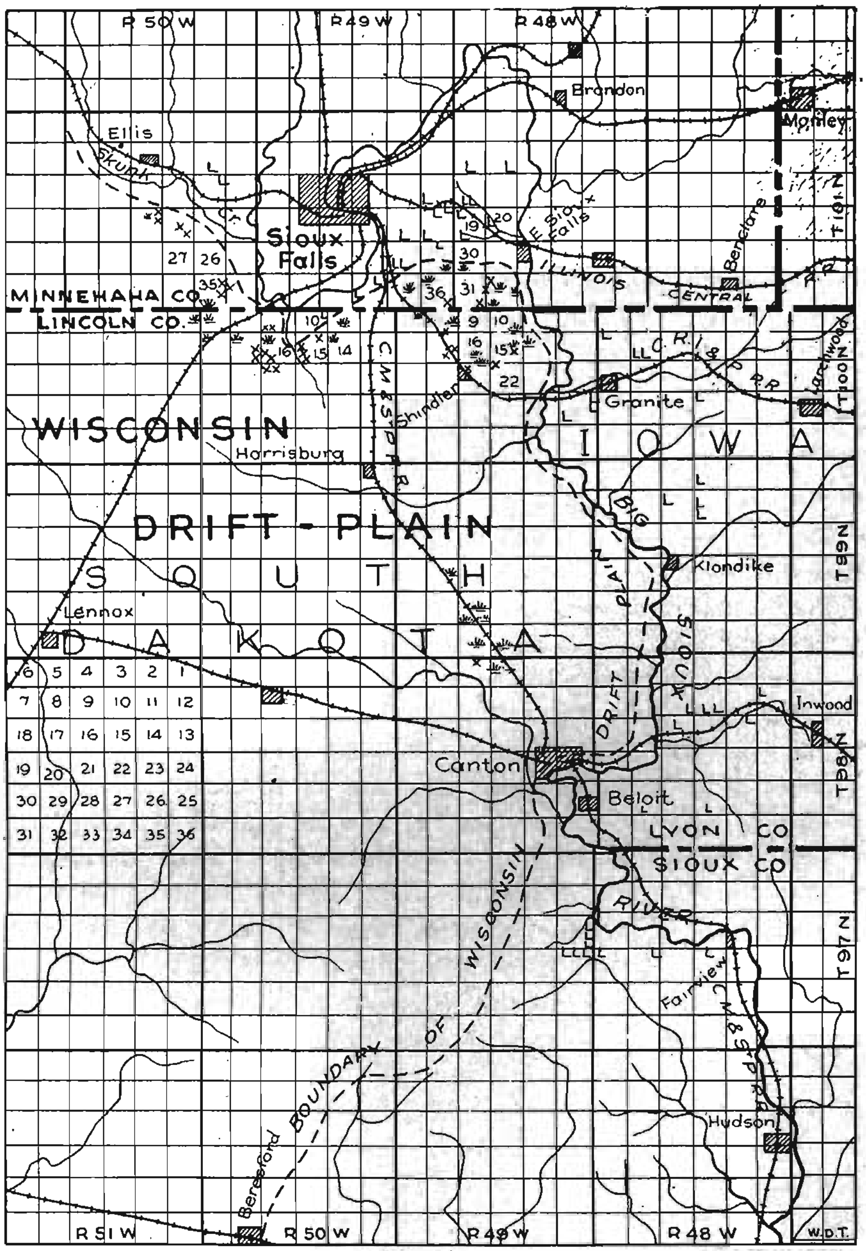
[37]Carman, J. E., The Wisconsin Drift-Plain in the Region about Sioux Falls: Proc. Iowa Academy of Science, Vol. XX, pp. 237-250, 1913.

Iowa side. These contrasts in the topography and elevation of the areas on opposite sides of the Big Sioux river are well shown in the northeast corner of the Canton topographic sheet of the U. S. Geological Survey.

Directly east from Sioux Falls, the topography is erosional with a relief of fifty to seventy-five or even a hundred feet. The distance between the two limbs of the northward loop of the Big Sioux valley is here only four to six miles (Plate XVIII), and the small creeks have cut back from either direction until all the area is well drained. The slopes are moderately steep, but rounded, indicating submature dissection; the region is covered with loess, which is seen in many road-cut exposures; the surface material, which is derived from the loess, is without grit of any sort; and no pebbles or bowlders appear at the surface. In the more dissected parts, near the large valleys, the fresh, brownish gray phase of the Kansan drift can be exposed. The region belongs to the loess-covered Kansan drift-plain.

Extending in an east-west direction through sections 30 and 29 of Township 101 North, Range 48 West, southwest of East Sioux Falls, is a ridge which rises to an elevation approximately that of the major divides to the north, has a rounded crest and apparently is erosional. The north slope has broad valleys leading down to the creek of sections 19 and 20, the bed of which is 100 feet lower than the crest of the ridge. This is the ridge described by Professor Todd (page 294) and interpreted by him as a part of the outer moraine. From the crest of this ridge one overlooks the region to the north and the south. To the north is the rolling country of erosional topography noted above. To the south of the crest, the slope descends thirty to fifty feet in the first half mile and then an even plain of slight relief continues to the south and southwest.

In sections 31 and 32 (Township 101 North, Range 48 West), on this plain, there is a relief of fifteen to twenty-five feet, with many undrained depressions which during the wet season contain small ponds (Plate XVIII). Just east of the southwest corner of section 32 there is a small depression occupied by a pond and not more than fifty yards from the edge of a narrow valley which is cut to a depth of thirty to forty feet below the plain.



Map of the Sioux Falls-Canton region. The broken line shows the eastern boundary of the Wisconsin drift-plain in Dakota. L—loess exposures, X—bowlders, ⩛—undrained depressions.

Other ponds lie just to the east in similar positions with reference to this valley, and at the quarter-section corner on the east of section 32 is an undrained depression within a short distance of the edge of the Big Sioux valley. This plain continues southward and southwestward to Shindler and beyond. North of Shindler the relief is ten to twenty feet, and undrained depressions with swamps are present in every section. The location of a number of these is shown in Plate XVIII. Typical examples appear in the southeast corner of section 36, Township 101 North, Range 49 West, the southwest and southeast quarters of section 31, Township 101 North, Range 48 West, the northwest corner of section 9, the east part of section 8, and at several places in sections 17, 8 and 7, all in Township 100 North, Range 49 West, along the Chicago, Rock Island and Pacific railway northwest of Shindler.

The loess loam, so usual in the Kansan area, is absent here, and the drift continues to the surface, or is overlain by black soil. A field in the southeast quarter of section 31 showed a gravelly, pebbly soil turned up by recent plowing, and the road beds contain pebbles and sandy material which produces a grating sound beneath wagon wheels. A few bowlders lie on the surface or have been gathered up and piled along the fences. These may be seen along the west line of section 32, southwest of East Sioux Falls, in sections 22 and 15, east of Shindler, and a pile of them may be seen from the railway train just southeast of the station at Shindler. They are numerous in sections 15 and 16 of township 100 north, range 50 west, and were seen at a number of places farther northwest (Plate XVIII).

The erosion valleys of this plain are narrow and steep sided. They are found only along the Big Sioux valley, and even here have determined the topography of only a small part of the area they drain. The usual relief features of the plain are low hills and broad swales interspersed with shallow undrained depressions. Most of the broad swales are followed by streams, but these streams did not make the valleys which they occupy. They made only the narrow, shallow channels in which they flow. The low hills and ridges show by their position and form that they were not made by erosion, but that, like the broad winding depressions in which the streams flow, they are constructional.

Sufficient characters have now been given to indicate the type of plain with which we are dealing. It is a glacial plain with very definite characters, and is in decided contrast with the erosional area to the north, and with the region on the Iowa side.

THE WISCONSIN DRIFT-BOUNDARY NEAR SIOUX FALLS.

The boundary between the erosional topography and the glacial topography is not sharp in all cases, but the transition from the one to the other takes place within a quarter to half a mile. The boundary is shown in Plate XVIII by a heavy broken line. From the Big Sioux valley about a mile south of East Sioux Falls it extends westward through the south parts of sections 29 and 30 along the south base of the ridge described on page 302. In the east part of Sioux Falls township (T. 101 N., R. 49 W.) its course changes to southwest, parallel with the Big Sioux. It continues in this direction for about four miles, to the northeast part of section 16 of Township 100 North, Range 50 West and thence bends abruptly to the north and follows a small creek valley through section 9 to the Big Sioux. Southeast of this boundary there is a slightly rolling glacial plain with undrained depressions and many bowlders, and drift extends to the surface. To the northwest the surface is rolling to rough, is entirely controlled by drainage lines and the material at the surface is loess or pebbleless loam.

From the mouth of the creek valley on the north line of section 9, the boundary is the edge of the Bix Sioux flood-plain west and north to the union of Skunk creek valley with the Big Sioux valley. From here the border lies along the south edge of the Skunk creek flat, and extends northwest through the center of Township 101 North, Range 50 West. The part of this township to the south of Skunk creek is an undissected glacial plain while that to the north is maturely dissected and the surface exposures are of loess. The contrast of the topographies on opposite sides of this valley is very pronounced and furnishes an excellent example of glacial versus erosional topography.

In this entire distance along the Wisconsin margin from the Big Sioux opposite the state line to the center of Township 101 North, Range 50 West, a distance of fifteen to seventeen miles, there is not a single hill that might be called a terminal moraine hummock, and the marginal part of the glacial plain is no more uneven than that more distant from the margin, except for irregularities due to recent erosion or to incomplete obliteration of pre-Wisconsin surface features.

Professor Todd described the course of the "outer moraine" across this area in the following words:[38] "Beginning on the west side of the Big Sioux, about a mile north of the northern boundary of Iowa, a high massive ridge begins to extend westward and southwestward around the Great Bend of the Big Sioux, and continues its westerly course to near the southwest corner of township 101, range 51." Near the Big Sioux valley, south and southwest of East Sioux Falls this ridge is prominent, but it is less prominent westward and in southeastern Sioux Falls township is represented only by disconnected hills. These features, apparently taken by Professor Todd as morainic, are all on the Kansan drift just beyond the actual Wisconsin drift-margin and are not morainic, but erosional. However, the contrast between the glacial plain to the south and the erosional topography to the north was detected and its true significance realized. Professor Todd states that westward from the Great Bend, this ridge "continues its westerly course to near the southwest corner of township 101, range 51." A broad ridgelike elevation does continue westward along the county line from the Great Bend, but this elevation does not mark the margin of the Wisconsin drift, for as noted above the southern part of township 101 North, Range 50 West, south of Skunk creek, belongs to the Wisconsin drift-plain.

THE DRIFT.

This separation of the Kansan and the Wisconsin drift-plains is based on physiographic features, although the bowlders of the Wisconsin drift and the loess-covering of the Kansan areas are contributory lines of evidence. The Wisconsin drift is very hard to distinguish from the Kansan, at least in the marginal

[38]U. S. Geol. Survey Bull. 158, p. 35.

part of the Wisconsin drift-area, or else the Wisconsin drift is very thin. In a few places the drift observed is not the typical Kansan and may be Wisconsin; but most of the exposures studied apparently are Kansan. On the basis of the characters of the drift alone one would not separate the areas; but the conclusive evidence is the topography, and with this agree the absence of a loess-covering over the Dakota plain, the presence of bowlders on the surface, and the questionable drift of the region.

Southeast of Shindler, along the Chicago, Rock Island and Pacific railway, where it descends to the Big Sioux valley, there are a number of drift cuts. The plain above is Wisconsin, but the drift exposures are Kansan with the possible exception of the first cut southeast of Shindler, which is at the very edge of the plain just where the descent begins. In this cut, there is near the surface, loose, sandy drift which breaks out in rounded fragments and crumbles to a sandy, mealy clay when crushed in the hand. It grades downward to a harder, more plastic clay, which breaks with the more definite Kansan fracture.

Just south of the northwest corner of section 36 of Sioux Falls township (Township 101 North, Range 49 West), yellowish brown sandy drift comes to the surface, except for a thin covering of soil. This is just inside the Wisconsin drift area and good glacial topography continues to the southeast. Only half a mile to the west but beyond the Wisconsin drift-boundary a road cut showed a loess-covering four to six feet thick over the Kansan drift (Plate XVIII).

At the northeast corner of section 10, Township 100 North, Range 50 West, just outside the Wisconsin drift-margin, there are several cuts in loess, one of which is twelve feet deep, and some of them show Kansan drift below the loess. About eighty rods south, a road-cut shows, at the surface, brownish gray drift with considerable sandy material and a few pebble bands. Eight feet lower on the slope, the drift rests on brownish yellow loess several feet in thickness, the base of which is not exposed. Apparently the Wisconsin ice overrode loess at this place, and covered it with Wisconsin till.

We are accustomed to think of the drifts of different ice-epochs as presenting each its own characteristic lithological features, but if two ice-sheets advanced over the same route and eroded the same rock formations, there is little reason why the drifts should differ in composition. The Wisconsin drift was obtained from the same rocks as the Kansan drift, or is in large part simply reworked Kansan drift, so that we should not expect the two sheets of drift to be distinctly different. However, it is not believed that any large amount of the drift exposed in the deeper cuts, as along the railway southeast of Shindler, is Wisconsin. It is believed rather, that the amount of Wisconsin drift is small, amounting to only a few feet of material, much like the Kansan, and grading downward into the latter. Detailed work in the region will probably show that the Wisconsin drift differs slightly from the Kansan, so that it will be possible to differentiate them, but should this not prove true, the glacial plain remains, and this cannot be Kansan. It is a youthful glacial plain and nothing of this type is found in any known Kansan drift-region.

The Chicago, Milwaukee and St. Paul railway, extending south from Sioux Falls, crosses the border of the glacial plain just north of the county line, and continues southward across this plain through Harrisburg to Canton. At a number of places along this road swamps may be seen, and bowlders lie on the surface. It is evident that if the identity of the Wisconsin plain is established farther north, it should continue south to Canton. The writer has not seen the region southwest of Canton, but from the topographic map of the area it seems evident that the southeast border of this plain is approximately as given by Professor Todd, that is it runs from the point of the upland south of Canton, south by southwest through Beresford.

ABSENCE OF LOESS.

It has been noted already that loess is absent over the Wisconsin plain, but the matter is of such importance that a more complete statement is justified. The rugged region of the Iowa side is loess-covered, with numerous exposures in the road-cuts. The area within the east loop of the Great Bend between Sioux

Falls and East Sioux Falls, the area within the west loop of the Great Bend and that west of the Big Sioux and north of Skunk creek, are all loess-covered, as is also the rugged area south of Canton. In contrast with this loess-covered rugged area the Dakota plain is free from loess. In Plate XVIII there are mapped twenty exposures of loess in the area north of the Wisconsin drift-plain to the east and west of Sioux Falls, nineteen exposures on the Iowa side, and nine exposures in the rugged area south of Canton.

Many of the loess exposures of Plate XVIII are taken from a map by Professor Shimek.[33a] On this map, Professor Shimek shows but one exposure of loess in the area which is included within the Wisconsin drift-plain of Plate XVIII, and this one is just at the edge of the Wisconsin drift-plain, in or near the west bluff of the Big Sioux valley. On the other hand he shows twelve exposures of loess within the east loop of the Big Sioux, sixteen along the Iowan upland between the state line and a point opposite Canton, and eleven in the upland south of Canton. The plotting of these loess exposures brings out the fact that the loess-covered area is identical with the area of erosional topography, while the area without loess is identical with that having a glacial topography.

SUMMARY.

The results of this study would fix the extent of the Wisconsin drift-plain essentially as determined by Professor Todd. The writer does not, however, agree with Professor Todd concerning moraines at the edge of the Wisconsin plain. It has been shown that the features taken by Todd as the Altamont moraine, from a point opposite the north boundary of Iowa westward to the south end of the Great Bend, are erosional hills and ridges of the Kansan plain just outside the Wisconsin boundary, and that the ridge stretching westward from the south end of the Great Bend is within the Wisconsin boundary since it has glacial topography to the north, as far as the valley of Skunk creek. The isolated hills along the west side of the Big Sioux between East Sioux Falls and Canton, called Altamont moraine by Todd, apparently are remnants of the Kansan plain, which

[33a] Bull. Geol. Society of America, Vol. 23, p. 131.

are made up of Kansan drift but were over-ridden by the Wisconsin ice. It is also probable that there is little true terminal moraine along the border southwest of Canton toward Beresford.

In summary, the evidence submitted may be brought together as follows:

(1) The Dakota plain has a slightly rolling surface, with a relief of fifteen to twenty-five feet, while the region to the north, east and southeast, is rugged with a relief of 100 to 150 feet.

(2) The Dakota plain has an altitude fifty to a hundred feet below the altitude of the divides of the adjoining regions to the north, east and southeast.

(3) The relief features of the Dakota plain are principally low mounds and broad swales, interspersed with shallow undrained depressions. The few erosion valleys are narrow and steep sided and have determined the topography of only a narrow belt on either side. This is a definite glacial surface and the time which has elapsed since its formation is comparatively short. The relief features of the adjoining region are those produced by erosion by running water and have advanced to the submature stage of the cycle.

(4) The Dakota plain is free from loess, while the region to the north, east and southeast has a loess covering.

(5) Bowlders and bowlderets are numerous on the Dakota plain, while in the area to the north, east and southeast, bowlders are rare, except in the beds of ravines that are being actively degraded.

(6) The Dakota plain has a dark, pebbly, gritty soil, while over the surrounding area there is a pebbleless loam derived from the loess.

This combination of characters found on the Dakota plain calls for an entirely separate glaciation at a very recent geologic time. The conclusion then is, that the plain extending from the boundary along the north line of Lincoln county, south through Shindler and Harrisburg to the upland south of Canton, and east to the Big Sioux valley, was covered by a part of the Dakota lobe of the Wisconsin ice-sheet and is a Wisconsin drift-plain, while the areas to the north, east and southeast belong to the loess-covered, maturely eroded Kansan drift-plain.

As mapped by Professor Todd the east edge of the Dakota lobe, from the head of the Coteau des Prairies extended southward through Codington, Hamlin and Brookings counties along the west side of the Big Sioux valley, as shown in Plate XVII.[39] The Altamont moraine was mapped as offsetting fifteen to twenty miles to the west in northern Lake county and then continuing southward, at a distance of twenty to thirty miles west of the Big Sioux, through western Lake, northeastern McCook and southwestern Minnehaha counties, and eastward along the south line of Minnehaha county to the Big Sioux valley. From the results of the work on the Dakota side noted above (page 301), which show that the boundary extends northwest along the south side of Skunk creek, and from the description of western Minnehaha and Lake counties given by Professor Todd,[40] the writer is led to believe that the actual boundary of the Wisconsin drift continues northward across western Minnehaha and eastern Lake counties and does not make the offset which the moraine may make.

Mr. Leverett retraced this east boundary of the Dakota lobe in 1912 but his results have not yet been published. His work verifies the tracing of that part of the boundary given above (page 301).

The distance between the Des Moines and the Dakota lobes of the Wisconsin ice at the north line of Iowa was forty-six miles, but they remained separate 150 miles farther north. The area between these two lobes contains the headwaters of the Big Sioux river. The Altamont moraine of the Des Moines lobe in Minnesota is located approximately on the earlier divide, and the water draining southwestward from the Des Moines ice lobe was stopped by the edge of the Dakota lobe. The various streams were here united, and flowing southward along the course of Big Sioux river, carried away the drainage of the two ice-edges.

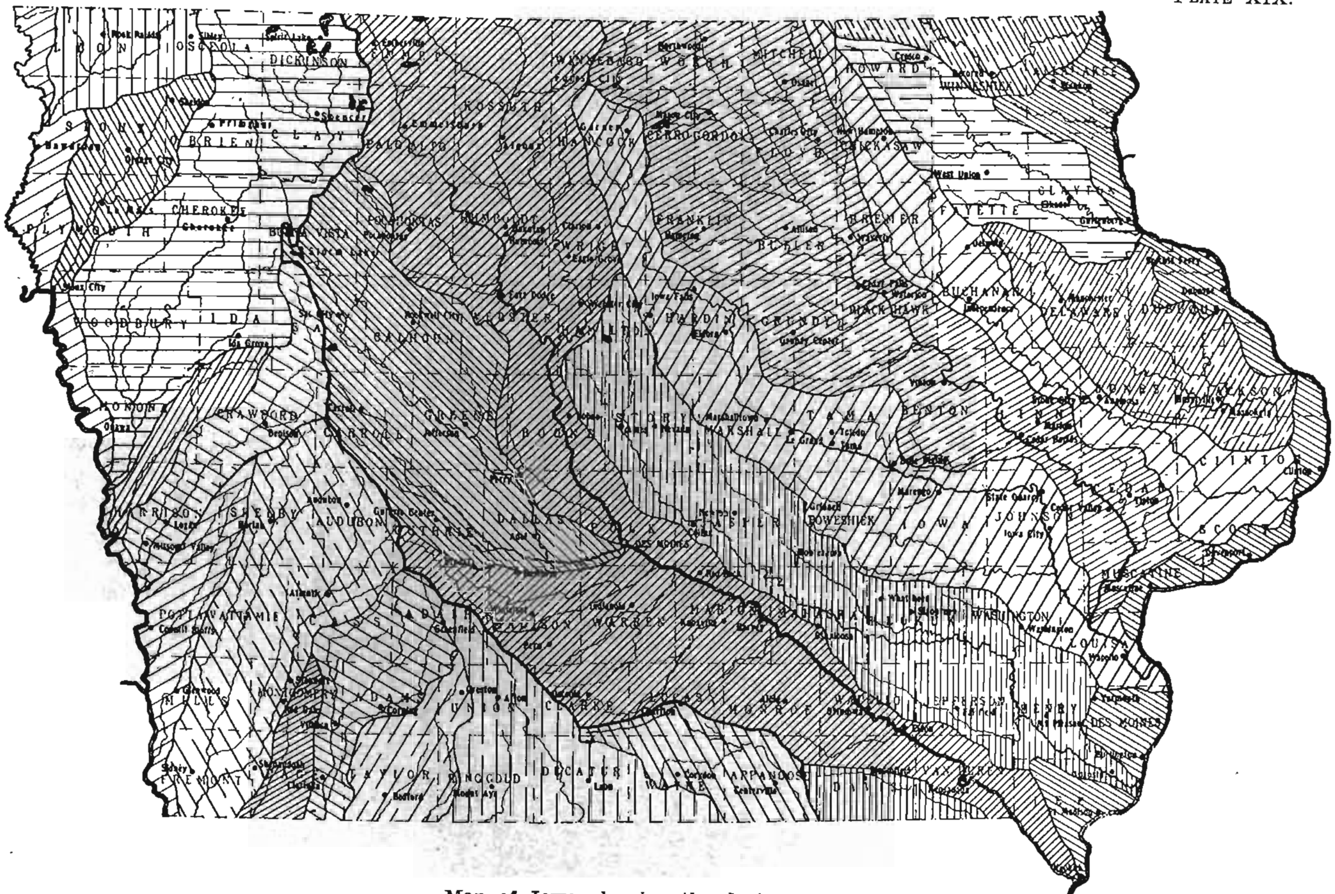
[39]U. S. Geol. Survey Bull. 144, Pl. 1.
[40]U. S. Geol. Survey Bull. 158, p. 36.

Drainage Changes Caused by the Wisconsin Ice.

The eastern three-fourths of the state of Iowa drains southeastward by long parallel streams to the Mississippi river. The western quarter of the state drains southwest by south through shorter streams to the Missouri river. The parallelism of the major streams both to the southeast and to the southwest is a notable feature of the drainage of Iowa (Plate XIX). The divide between these two great drainage basins has a northwest-southeast direction through southwestern Iowa, but in western Carroll county, it takes a more northerly course which is followed to the Minnesota state line.

The divide intersects the south boundary of Sac county east of the middle of the south line of Viola township, crosses the east end of Wall lake outlet and extends northward through central Sac county, forming the divide between Indian creek and Boyer river (Plate XV). It passes westward along the south side of the Storm lake basin and northward along the divide through Alta (Plate XIX). Four miles north of Alta it doubles back around the head of the small creek which enters the northwest corner of Storm lake and extends southeast almost to Storm Lake, rounding the head of Brooke creek, which flows north to the Little Sioux. North of the head of Brooke creek the divide is in the Wisconsin drift-area, and its course to the northward is less definite. It extends north and east through central and northeastern Buena Vista county between the headwaters of Raccoon river on the southeast, and the tributaries of the Little Sioux on the northwest. It crosses the southeast corner of Clay county, follows north along the Ruthven moraine two to four miles east of the west line of Palo Alto and Emmet counties, crosses the northeast corner of Dickinson county and enters Minnesota about five miles west of Des Moines river (Plate XIX).

The divide continues northward in southeastern Jackson county, Minnesota, for twelve miles and then bends westward around the headwaters of the Little Sioux, offsetting twenty-four miles to the west and in this distance swinging six miles to the south. Here, northwest of Worthington, the divide changes its direction to north of northwest, and holds this course for



Map of Iowa showing the drainage basins.

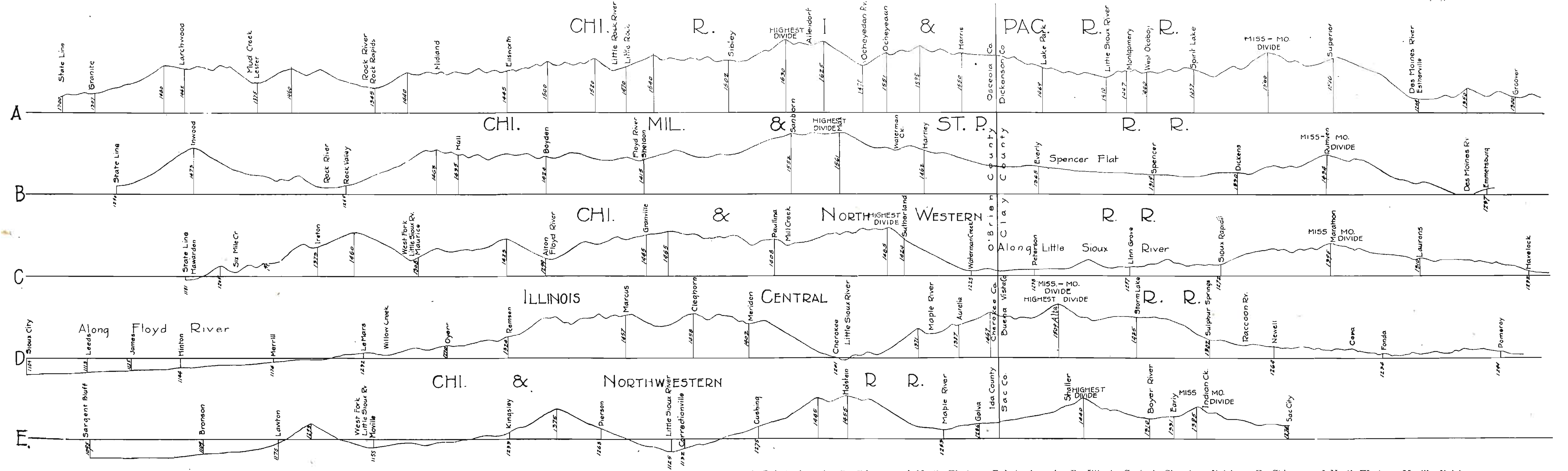
more than a hundred miles along the crest of the Coteau des Prairies.

From the south line of Sac county to Storm Lake the divide is just west of the boundary of the Wisconsin drift-region. North of Storm Lake the divide lies within this drift-region, but, as far as Ruthven it is only five to ten miles east of the boundary. The boundary thence angles westward to such an extent that on the state line the divide is thirty-six miles within the Wisconsin drift-area, but the westward course of the divide across the headwaters of the Little Sioux brings it back to within a few miles of the Wisconsin drift-boundary northwest of Worthington, in which position it continues on to the northwest along the crest of the Coteau des Prairies.

DRAINAGE CHANGES IN THE LITTLE SIOUX RIVER BASIN.

Course of the Mississippi-Missouri Divide.—The Mississippi-Missouri divide northwest of Worthington, Minnesota, agrees in direction with the part south of Storm lake. Between Worthington and Storm Lake a great reëntrant carries the divide to the east about the headwaters of Little Sioux river. But for this irregularity, the course of the divide would continue northward from Alta through western Buena Vista, western Clay or eastcentral O'Brien and central Osceola counties; it would cross the state line just east of Bigelow, Minnesota, and would join the present divide where it changes its direction northwest of Worthington. This raises the question, may this not have been the real watershed of the state. In other words may not the region now drained by the Little Sioux above northeastern Cherokee county formerly have drained southeastward to Mississippi river? Two other lines of evidence, bearing on the subject, should be examined before the question is decided.

Altitude of the Mississippi-Missouri Divide.—The divide between the drainage of Mississippi and Missouri rivers south of Sac county, and of that portion northwest of Worthington is along the highest land between these two rivers; but in most places within the area under discussion this is not true. The range of hills (Ruthven moraine) standing well above the region to the east and west, which forms the divide in western Palo



Profiles of railways crossing northwestern Iowa. A—Chicago, Rock Island and Pacific, Sioux Falls branch; B—Chicago, Milwaukee and St. Paul, Dakota branch; C—Chicago and North Western, Dakota branch; D—Illinois Central, Cherokee division; E—Chicago and North Western, Moville division.

Alto and Emmet counties, has an altitude of 1425 to 1475 feet above sea level, while the watershed west of the Waterman and Ocheyedan drainage basins has an altitude of 1450 to 1500 feet in southeastern O'Brien county, and rises northward to more than 1600 feet in northern Osceola county.

The comparative altitude of these two divides is well shown by a study of the profiles of the railways that cross the region. The Chicago, Rock Island and Pacific railway in the north row of counties crosses the Mississippi-Missouri divide near Superior in northeastern Dickinson county at an altitude of about 1560 feet, but the altitude continues to increase westward until in central Osceola county, just west of the Ocheyedan valley it is about 1630 feet (Plate XX, profile A). The Chicago, Milwaukee and St. Paul railway in the north part of the second row of counties crosses the Mississippi-Missouri divide in western Palo Alto county, near Ruthven, at an altitude of about 1440 feet, but the highest divide is crossed more than thirty-five miles farther west, just east of Sanborn in northern O'Brien county, at about 1560 feet (Plate XX, profile B).

The Des Moines and Sibley branch of the Chicago, Rock Island and Pacific railway crosses the Mississippi-Missouri divide near Leverett, in northeastern Buena Vista county, at an altitude of about 1370 feet, but it continues to rise gradually to the northwest across Clay and northeastern O'Brien counties, and has its highest altitude near Melvin in southern Osceola county at more than 1580 feet. The Dakota branch of the Chicago and North Western railway crosses the Mississippi-Missouri divide near Marathon in northeastern Buena Vista county, at about 1400 feet, but the divide crossed just west of Sutherland in southeastern O'Brien county has an altitude of about 1500 feet (Plate XX, profile C). South of the Little Sioux river the next line is the Illinois Central railway which, at Alta (1509 feet) in southwestern Buena Vista county, attains its greatest altitude within the state on the crest of the Mississippi-Missouri divide (Plate XX, profile D).

All the highest points crossed by the railways in the two north rows of counties are on the divide west of the Little Sioux drainage basin in O'Brien and Osceola counties, along the course, which, as noted above, would be a direct continuation of the divide to the north and south. The evidence therefore of altitude would support strongly the idea that the true watershed of the state should continue west of north from western Buena Vista county through O'Brien and Osceola counties.

Pattern of Drainage.—A study of the drainage map of Iowa (Plate XIX) shows that the streams which flow southeastward to the Mississippi have their upper courses almost parallel with the divide, and draw away from it very gradually while those which flow southwestward toward the Missouri have their headwaters almost normal to the divide. As a result of this difference, almost the whole of the east side of the Mississippi-Missouri divide is drained by the tributaries of Des Moines river, the longest and largest of the southeastward flowing streams, while nearly every important stream of southwestern Minnesota and western Iowa, except the Floyd, has its headwaters on the west slope of the divide.

Again, Little Sioux river and its tributaries present exceptions. It drains the west side of the Mississippi-Missouri divide in the reëntrant between Storm Lake and Worthington, Minnesota, a distance of about 125 miles, and for most of this distance runs parallel with the divide. Its upper course is southward across Dickinson and northern Clay counties. At Spencer it changes direction and flows east for four miles to the mouth of the Dickens outlet, thence south to Gillett Grove, from that point southwest to Sioux Rapids, and thence west and north of west to the southeast corner of O'Brien county. Here it changes to a direction southwest by south and follows this course to the Missouri river (Plate XIX).

Ocheyedan river flows southeast across eastern Osceola and northwestern Clay counties to its union with the Little Sioux at Spencer. With its tributary, the Little Ocheyedan, it drains, by streams leading to the southeast, the east slope of the high north-south watershed of central Osceola county. Stony creek in southwestern Dickinson and northwestern Clay counties also has a course east of south. Willow creek in southwestern Clay county flows east by southeast to Little Sioux river. Waterman creek, which drains the east slope of the high watershed of eastern O'Brien county, flows east of south to its union with the Little Sioux. All these western tributaries of the Little Sioux, as well as the Little Sioux itself above the bend east of Spencer have courses leading southeast, which would fit the Mississippi drainage better than that to which they now belong. Southwest of the northeast corner of Cherokee county, the course of the Little Sioux is typical for the streams of western Iowa. Between the bend east of Spencer and northeastern Cherokee county, the course of the Little Sioux is characteristic of neither system, but appears to be accidental. Judged by the pattern of drainage, the high watershed of O'Brien and Osceola counties fits better as the great watershed of the state than the present divide along the moraine of western Palo Alto and Emmet counties.

As a result of the peculiar course of the Little Sioux with respect to its western tributaries, some very indirect water routes exist. Where the Little Sioux leaves the southwest corner of Clay county, it is only nine miles from the headwaters of Willow creek, although it is more than fifty miles by the route the water follows. The distance between the Ocheyedan valley in northeastern O'Brien and the Little Sioux valley in southeastern O'Brien is only twenty-one miles, but the water route is eighteen miles eastward into Clay county and follows an irregular course of more than sixty miles.

Conclusions.—The course of the divide northwest of Storm lake has now been tested in three ways: The position or directness of the course, the altitude, and the pattern of drainage. All these lines of evidence indicate strongly that the true Mississippi-Missouri divide north of Alta should continue west of north through O'Brien and Osceola counties along the west side of the Little Sioux drainage basin north of northeastern Cherokee county, and that the region drained by the Little Sioux and all its tributaries above northeastern Cherokee county, once was drained southeastward by way of Des Moines river to the Mississippi.

Possible Pre-Wisconsin Stream Courses and the Successive Drainage Changes.—If this conclusion is accepted the questions at once arise, what were the courses followed by these streams in pre-Wisconsin time, and what were the successive changes, with their causes, that brought about the present drainage.

The Little Sioux drainage system above Spencer consists of two principal streams, the Ocheyedan and the Little Sioux proper. Above their union the Ocheyedan river is longer than the Little Sioux, and below their union at Spencer, they continue eastward for four miles in a course which is the direct continuation of the Ocheyedan valley, and this course is then continued farther eastward by the Dickens outlet which enters the Little Sioux at its southward bend. It seems therefore that the Ocheyedan should be considered the headwaters of the system. Professor Macbride inferred[41] that the pre-Wisconsin course of the Ocheyedan was eastward up the Dickens outlet past Ruthven to the Des Moines river and carried with it the drainage of the present Little Sioux system above its southward bend east of Spencer. This interpretation probably is correct, and some of the low marshy areas of eastern Freeman township, as in sections 27, 26 and 24, and Elbow lake south of Ruthven may mark parts of this course.

The small creek draining southwestern Sioux township was part of this eastward drainage, and another tributary probably headed southward along the course of the present Little Sioux valley toward Gillett Grove, and received as part of its drainage the creek which drains the central part of Gillett Grove township. This latter creek and others of the adjoining sections now join the Little Sioux with an acute angle down stream. The bend east of Spencer apparently was caused by the damming of the eastward flowing stream (pre-Wisconsin Ocheyedan) by the Wisconsin ice-front. The ponded waters then ascended the valley which headed southward toward Gillett Grove, and broke over to another valley leading southward.

A short distance below its southward bend at the mouth of the Dickens outlet, the Little Sioux valley is narrower and deeper and the sides are steeper. At Gillett Grove the valley reaches the Wisconsin drift-boundary, and from here southwest to Linn Grove it follows this boundary. Throughout southeastern and southern Clay, northern Buena Vista and southwestern

[41]Iowa Geol. Survey, Vol. XII, p. 334, 1901.

O'Brien counties, the valley is narrow and deep, and the valley sides rise steeply to the level of the upland plain, 100 to 125 feet above the river (figure 38). This course apparently was established during the Wisconsin epoch, but the courses of the various pre-Wisconsin valleys which are represented in this valley, are only partly known. The successive damming of eastward flowing streams, with the resultant ponding and breaking over to more southerly and westerly valleys, would, could we but read it correctly, be an interesting and instructive record of events.

FIG. 38. Looking north across the Little Sioux river valley at Sioux Rapids. In the background are shown the steep bluffs and the even sky line formed by the edge of the Kansan drift-plain. (Macbride, Iowa Geological Survey, volume XI, p. 481.)

Within the Wisconsin drift of southeastern Clay county there are several long marshy depressions, some of which probably were pre-Wisconsin valleys, while others were made during the Wisconsin epoch. The valley of Elk creek in Logan township may be a pre-Wisconsin valley. Its course and characters were described on page 267. A slough almost half a mile wide and more than two miles long, with a direction west of north lies southwest of Webb in western Garfield township, and is continued to the north through Herdland township by a valley which opens into the Little Sioux. This is probably the course of a pre-Wisconsin valley. From the south end of this slough, another leads west across the north part of section 31, Garfield township, and the north part of section 36, Herdland township, and a valley continues this course west through sections 35 and 27 to the Little Sioux.

Willow creek enters the Little Sioux valley from the west in western Herdland township. In pre-Wisconsin time this creek probably flowed southeast along the present Little Sioux valley to section 27, and then eastward across sections 27, 35 and 36, Herdland township, and 31, Garfield township, by the low course noted above. This was apparently the chief stream of southern Clay county. Its course probably continued southeastward across Pocahontas county to Des Moines river, although it is possible that it may have turned southward to the headwaters of the Raccoon river. Another possible course for the pre-Wisconsin Willow creek is northeast along the present course of the Little Sioux to Gillett Grove, and thence by way of Elk creek valley eastward through Logan township toward the Des Moines river. This would account for the position of the Little Sioux valley from Gillett Grove to the mouth of Willow creek, as well as of Elk creek valley through Logan township, but it is not so plausible a course as that which continues the present direction of Willow creek south by southeast.

The present course of the Little Sioux valley westward along the north line of Buena Vista county and through the southwest corner of Clay county, probably is composed of parts of several older valleys; but it may have been largely one valley similar to the present Willow creek valley, which it parallels closely. A valley now enters the Little Sioux from the east at the bend of the river east of Sioux Rapids, and is followed by the Chicago and North Western railway from its head in the glacial marshes toward Marathon, down to the Little Sioux. A pre-Wisconsin stream in the Little Sioux course to the west may have flowed eastward along the course of this valley. Other small creeks entering the Little Sioux in sections 12 and 11 of Barnes township and section 13 of Brooke township may mark the southeastward continuation of courses of pre-Wisconsin streams which followed parts of the present Little Sioux course.

It is, however, not necessary to assume that there were pre-Wisconsin valleys along all this course of the Little Sioux. From Gillett Grove to Linn Grove its course is along the Wisconsin drift-margin, and since the general slope of southern Clay county is to the southeast, the waters obstructed in their natural course may have followed the edge of the ice and so determined the location of the valley. Where the drainage did not follow the ice-front, low passes may have determined the path from one drainage basin to another.

In pre-Wisconsin time Brooke creek was on the east side of the great watershed. Its upper part probably drained to the south and then passed eastward across Washington township to Raccoon river, and possibly the entire drainage course was reversed. When this valley, probably in section 21 of Washington township, was closed by the Wisconsin ice, the water was ponded and broke over to the north along the ice-margin, and then with the greater ponded areas from the northeast, broke across the great watershed along the present course of the Little Sioux.

The pre-Wisconsin Waterman creek might have belonged to either the Mississippi or the Missouri drainage. Its course through eastern O'Brien county has a direction a little east of south, and is reasonably direct as a continuation of the Little Sioux valley to the southwest. It would also have been well in accord with the Mississippi drainage pattern had it turned eastward at its present mouth, and followed the course of the Little Sioux past Peterson. A similar bend is made by the Ocheyedan river in northwestern Clay county. Farther to the southeast the course of this stream may have been eastward along the Little Sioux valley of northern Buena Vista county, or more probably southward by way of Brooke creek valley and eastward across Washington township, to Raccoon river. This interpretation would extend the headwaters of the pre-Wisconsin Raccoon to the north line of O'Brien county, making it a much longer stream than it is at present.

If Waterman creek flowed southwest to the Missouri system, the great watershed crossed the course of the present Little Sioux valley near Peterson, and continued northward along the divide east of Waterman creek to northeastern O'Brien county and then passed around the headwaters of Waterman creek to the high divide of southern Osceola county. If Waterman creek flowed southeast to the Mississippi system, the great watershed crossed the present course of the Little Sioux near the O'Brien-Cherokee county line, and continued northward along the divide west of Waterman creek to the high divide of southern Osceola county. The altitude of the divide to the west of Waterman creek is seventy to a hundred feet higher than the divide to the east, and its course is more direct. However, the Little Sioux valley at Peterson is narrowed and has more the appearance of being a cut across a divide, than has the valley at the north line of Cherokee county. Also the pre-Wisconsin gravel benches high up on slopes of Waterman creek valley seem to pass into the similar benches in the Little Sioux valley to the southwest, as if these valleys were continuous at the time the gravel was deposited. The evidence does not justify a positive statement and there is really little choice between the two possible courses, but the writer believes that the watershed east of the Waterman, although lower, was the Mississippi-Missouri divide.

DRAINAGE CHANGES IN THE BOYER RIVER BASIN.

A few miles south of Alta the Mississippi-Missouri divide extends in an east-west direction for six miles along the ridge between the headwaters of Boyer river and the Storm lake basin. Thence it extends to the south along the divide east of Boyer river to Wall lake outlet in southern Sac county. This offset is not great, but still the divide to the west of Boyer river is the more direct southward continuation through Sac county of the high watershed of western Buena Vista county. Also the altitude of the divide west of Boyer river is fifty to eighty feet higher than the present Mississippi-Missouri divide to the east (Plate XX, profile E). The altitude decreases southward from 1509 feet above sea level at Alta, to 1440 feet where it is crossed by the Chicago and North Western railway a mile east of Schaller, and to 1400 feet east of Odebolt.

The pattern of drainage on opposite sides of the Mississippi-Missouri divide through Sac county is the same, with Indian creek on the east and Boyer river on the west following parallel courses, east of south. Both are typical of the drainage to the east. The pattern on opposite sides of the divide west of the Boyer is different. The Boyer heads on the east slope of the great watershed, in southern Buena Vista county, and flows almost parallel with it, in a direction east of south, for more than twenty miles to southern Sac county, while on the west slope in this same distance, six different creeks, tributaries of the Maple river, have their headwaters normal to the course of the watershed.

Judged by the position or direction of its course, its altitude, and the pattern of drainage, the divide west of Boyer river was the great watershed as far south as southern Sac county.

In Levey township west of the town of Wall Lake, the Boyer river changes its direction from east of south, to southwest and flows in a direct course to Missouri river. Above this bend the Boyer flows through a broad open valley with gentle slopes Southwest of the bend it enters a narrow steep-sided valley that cuts through a high, rugged region which connects the high watershed west of the upper Boyer with the watershed, which, beginning in the northwest corner of Carroll county, continues southeast across southern Iowa, as both the highest watershed and the Mississippi-Missouri divide. Leading eastward from the bend is the abandoned Wall lake outlet (page 256), which crosses the Mississippi-Missouri divide and opens out on the Wisconsin drift-plain. This abandoned valley is wider and has gentler slopes than that now followed by Boyer river to the southwest. In pre-Wisconsin time the Boyer river turned eastward and passed through the Wall Lake outlet toward Raccoon river. When the ice-edge blocked this eastward drainage the ponded waters in the valley broke over a low place in the great watershed near Herring, in southwestern Levey township, and escaped to Missouri river. This course was cut so low during ice-occupancy, and the old valley to the east was so much filled that the Boyer continued to flow to the southwest and did not again take its eastward course to the Raccoon.

CONCLUSIONS.

As a result of the Wisconsin glaciation the earlier drainage to the Mississippi was diverted westward over the divide at two places and both diversions became permanent, at the expense of the Mississippi drainage. As a result of the diversion to the Boyer valley southwest of Wall Lake, the divide from southern Sac county to southern Buena Vista county was shifted five to seven miles to the east, and the drainage basin of the Boyer was increased by about 150 square miles. The diversion to the Little Sioux valley was much greater, for the divide was shifted thirty to thirty-five miles to the east, and the drainage basin of the Little Sioux was increased by almost 2,000 square miles. Within our area the present Mississippi-Missouri divide is the same as during pre-Wisconsin times for only seven to eight miles to the north and south of Alta in southwestern Buena Vista county.

CHAPTER III

THE KANSAN DRIFT-REGION.

The Kansan drift-region of northwestern Iowa is the area west of the Wisconsin drift-boundary. It includes all of Lyon, Sioux, O'Brien, Plymouth, Cherokee, Woodbury and Ida counties and parts of Osceola, Dickinson, Clay, Buena Vista and Sac counties (Plate XV). To the south it broadens out into the great Kansan drift-region of southern Iowa and northern Missouri. Northward it continues into southwestern Minnesota and eastern South Dakota, occupying the narrow area between the Des Moines and the Dakota lobes of the Wisconsin drift-region. From the northwest corner of Iowa southward to Canton the Big Sioux valley forms the boundary, with the Dakota lobe of the Wisconsin drift-plain to the west. South of Canton, the Kansan plain extends westward into southeastern South Dakota and northeastern Nebraska.

The Kansan drift-region, as interpreted in this report, includes in its eastern part that questionable area of northwestern Iowa which has been variously interpreted as covered with Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan or Kansan drift. This region was left outside the Wisconsin drift-sheet when the boundary of that area was retraced in 1909 and was studied during parts of the field seasons of 1910 and 1911. Various lines of evidence indicated that the eastern part of the area here called Kansan, the questionable area noted above, should be assigned to another drift-region, of an age intermediate between the Kansan and the Wisconsin. However, a super-Kansan drift-sheet could not be separated at most places and the topography did not seem to afford a consistent boundary line. The conclusion was reached that all of northwestern Iowa west of the Wisconsin boundary was of Kansan age. It was on the basis of this conclusion that the "Map of Iowa Showing Drift Sheets" published with Volume XXI of the Iowa Geological Survey, on which, in northwestern Iowa, the Kansan drift is represented as extending eastward to the Wisconsin boundary, was prepared. This map is reproduced as Plate XIV of this volume.

The publication of this report has been deferred from time to time because of certain questions concerning the area included in the eastern part of the Kansan drift-region and because work was being done in other parts of Iowa by members of the Iowa Geological Survey, and in southwestern Minnesota by Mr. Frank Leverett of the United States Geological Survey which it was thought might aid in the solution of the problem. The writer studied this questionable area further in 1913 and in 1916. During this time several conferences were held in the field with Director Kay of the Iowa Geological Survey, Mr. Leverett of the United States Geological Survey, and Mr. Lees, Assistant State Geologist of Iowa. In 1913 a western boundary of this questionable area, which the writer tentatively called the Intermediate drift-region, was traced. It is a very indefinite boundary which crosses eastern Lyon, northeastern Sioux, southwestern O'Brien, eastern Cherokee, northeastern Ida and southwestern Sac counties. The recognition of this Intermediate area rested almost entirely on topography, as a continuous drift-sheet could not be established.

In 1916, the writer in company with Professor Kay, attempted to clear up the matter of the age of the Intermediate area.

A more detailed study of the loesslike clay that overlies the Intermediate area convinced the writer that it is the leached loess and the continuation of the loess of the Kansan region farther west. This correlation of the loesslike clay with the loess makes the area preloess in age. This correlation, coupled with the practical identity of the drifts of the Kansan and the so-called Intermediate areas, and the indefinite boundary separating the two areas, led the writer to re-affirm the interpretation made in 1911, that all of northwestern Iowa west of the Wisconsin boundary belongs to the Kansan drift-sheet. It is believed that the somewhat peculiar topography which exists over the northeast part of the area here called Kansan, and which is not like the typical topography of the Kansan farther southwest, must be explained in some other way than by assuming that it was overridden by another ice-sheet which modified the topography but which left no continuous drift sheet.

Topography.

GENERAL CHARACTERISTICS.

The Kansan drift-region presents considerable diversity of topography. In its northeastern part, in Osceola, Dickinson, O'Brien and Clay counties the topography is slightly rolling, with, in part, local relief of only twenty to thirty feet. To the west and southwest the relief and ruggedness are greater, so that a rolling topography characterizes most of Lyon, Sioux, Plymouth, Cherokee and western Buena Vista and Sac counties, and in Woodbury and Ida counties the topography is rugged with a relief of 125 to 150 feet. The relief and ruggedness are less also farther from the rivers and nearer the inter-stream areas. The region contains level or almost flat areas; areas with slight relief, with long, gentle slopes; areas of moderate relief, well drained; rolling and rough areas with steep slopes; and sharply dissected areas with very steep slopes. These various types of topography have an orderly arrangement with respect to the chief drainage lines and in most cases grade gradually one to another.

The entire surface of the Kansan drift is in slopes, mostly definite, but in some cases so gentle as to be almost imperceptible.

The entire surface is therefore drained, although in some places poorly so. The drainage is characterized by long, direct stream courses, which for any particular locality, generally have a rather uniform direction, but diverge enough to make a dendritic stream pattern. Long, gentle slopes lead down on either side, making a topography of broad, open valleys. The steepness of the slopes varies with the relief.

The topography of the Kansan drift-region is in the main an erosional topography and is in the mature stage of the erosion cycle. The more level areas, however, do not seem to represent the original Kansan plain as do the level uplands of southern Iowa, but the region seems rather to have been eroded beyond the mature stage of the cycle.

DESCRIPTION OF THE TOPOGRAPHY.

The Slightly Rolling Areas.—Most of Osceola, O'Brien and Clay counties outside the Wisconsin drift-boundary have a topography that is only slightly rolling with areas that are almost level on the broader of the interstream spaces. A view of one of these level areas in northeastern O'Brien county is shown in figure 39. The largest of these level areas is found in western Clay county, in Lincoln, Clay and Lone Tree townships, between Willow creek and Ocheyedan river. The surface is so level that the natural drainage is poor, but there is sufficient slope for successful tiling and this is now a very productive farming region. Most of western Clay county within the Ocheyedan-Little Sioux loop has a slightly rolling topography, and at many places this comes to the very edge of the Little Sioux valley and with its gentle slopes is in decided contrast with the deep, narrow valley of the Little Sioux (figure 38).

Another fairly level area of considerable size is present along the Osceola-O'Brien county line between Melvin and Plessis, and smaller areas exist in northcentral Goewey, southeastern East Holman and southcentral West Holman townships of Osceola county, and in the westcentral and southwestern part of Lincoln township, O'Brien county. From the large area of slightly rolling topography of northern O'Brien county, narrowing areas extend southward along the divides between Floyd river and

FIG. 39. View across a level area of the Kansan drift-plain northwest of Hartley in northeastern O'Brien county. (Photo by Lees.)

Mill creek valleys, and between the valleys of Mill and Waterman creeks.

A very level area lies just south of the Wisconsin drift-boundary of southwestern Dickinson and southeastern Osceola counties, and similar though smaller areas are found east of Little Sioux river from Milford to Dickens and to Gillett Grove. The evenness of some of these areas may have been accentuated by the outwash from the Wisconsin ice-front (pages 267 and 272), but they apparently were very level before the Wisconsin epoch.

North of Spencer in the adjoining corners of Sioux, Meadow and Summit townships is another very level area, probably the flattest surface of the Kansan drift-plain. It is but little above the Little Sioux valley to the southwest, and is so level as to be poorly drained. The poor drainage of this district is due partly to a low ridgelike belt of sand hills along the edge of the Little Sioux flat, which has obstructed the drainage from the north (page 331).

Within this slightly rolling area of Osceola, O'Brien and Clay counties there are more strongly rolling belts along most of the larger valleys. These broaden southward along the valleys until the intervening, slightly rolling areas are entirely eliminated. Along some of the valleys, as the Little Sioux below Gillett Grove and the Waterman, a sharply dissected topography exists.

The Rolling Areas.—West and southwest of the slightly rolling area is a region that is characterized by rolling topography but which includes small patches of slightly rolling topography. This area without definite boundaries includes most of Lyon and Sioux counties, eastern Plymouth, Cherokee, and western Buena Vista and Sac counties. As noted above, prongs of this rolling topography extend northeast up the valleys into the region of slightly rolling topography and in turn prongs of the rugged topography to the southwest extend up the valleys into this area. On the intersteam spaces there are areas of slightly rolling topography. Such areas are found around Marcus in northwestern Cherokee county and northwest of Boyden in northern Sioux county.

The relief of this area may be as small as thirty to fifty feet or as great as a hundred feet or more. The drainage pattern is distinctly dendritic, the slopes are definite and the region is well drained. This area includes the best farm land of northwestern Iowa.

This area and that to the northeast have at many places small features that appear to be constructional. They are located on surfaces of more distinct erosional features, giving to the slopes a somewhat uneven or billowy appearance. These features suggest that a later ice-sheet overrode the region at a time when it had an erosional topography and left a thin but uneven veneer of drift. Such an explanation was carefully considered during the progress of the field work. It was not possible, however, to differentiate a drift material or find a definite southwest boundary for these apparently constructional features. The more prominent features are gravel hills on the Kansan drift (pages 362 to 372), and the billowy appearance of the surfaces of the erosional features is apparently due to an uneven mantle of loess which overlies the erosional surface (page 343).

The Rugged Areas.—Southwest of the rolling area the topography becomes more strongly rolling and passes into what may be called rough or rugged. This district includes a belt which widens southward along the Big Sioux in Lyon, Sioux and Plymouth counties (figure 40), and embraces all of Woodbury, all of Ida except the northeast corner, and the southwest corner of Sac county. This area has a topography like the typical Kansan of southern Iowa with which it is continuous southward.

FIG. 40. View of the Kansan drift topography along Broken Kettle creek in western Plymouth county. (Bain, Iowa Geological Survey, volume VIII, p. 321.)

The general relief of this region is 100 to 150 feet and the slopes are steep, but on some of the divides there are small areas of only moderately or slightly rolling topography. Such an area exists around Holstein in northern Ida county.

An area just east of the Missouri river valley in Woodbury and southwestern Plymouth counties has a topography of a bold, rugged type, characterized by steep slopes which are at many places almost bare of vegetation, by pointed hills, and by narrow ridges (figure 41). This belt has a thick deposit of loess and the topography is partly loess-formed. Five to ten miles from the river flats, with the decrease in the thickness of the loess, this topography grades into the more typical erosion topography of the Kansan drift-region.

Aggraded Areas.—At several places within the Kansan region, there are almost level areas that have been formed by the filling in of low areas with gravel. A good example is found west of

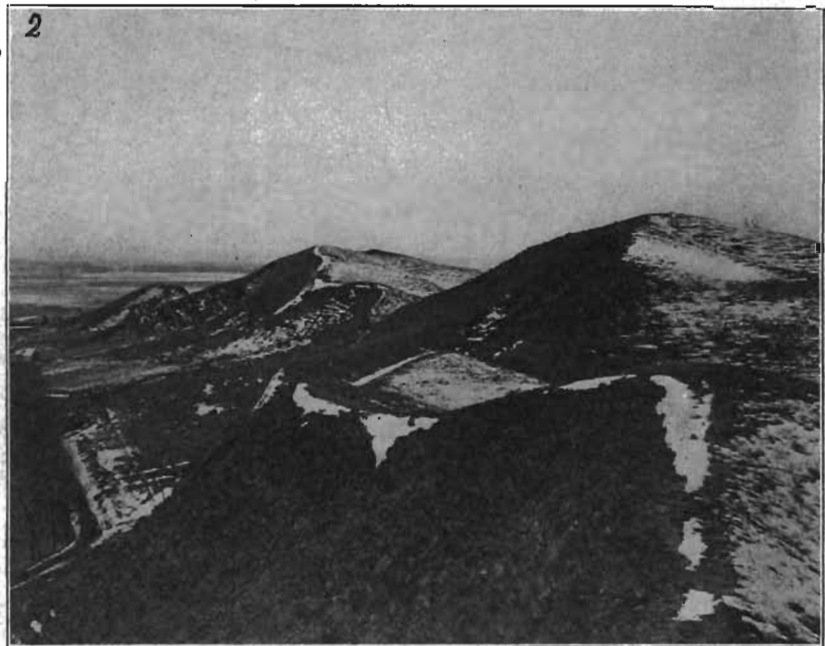


FIG. 41. The topography of the loess-covered region north of Turin, Monona county. Snow partly covers the surface. (Shimek, Iowa Geological Survey, volume XX, p. 289.)

Primghar in central O'Brien county, where several branches of Mill creek unite (page 403). Here a level area several square miles in extent is almost wholly underlain with gravel. Another lies east and southeast of Sibley in East Holman township, Osceola county, where areas extending some distance back from the present valleys are underlain with gravel (page 386).

Sharply Dissected Areas Along Valleys.—Along some of the larger valleys of the Kansan drift-region there are areas characterized by sharp dissection and considerable local relief, giving a very rugged topography along the valleys, although the inter-stream areas present rounded slopes and slight relief. This topography is found along the Little Sioux valley in Cherokee, southeastern O'Brien, and southern and eastern Clay counties. It exists also along the lower courses of the larger tributaries of the Little Sioux, as Mill, Waterman, Willow and Brooke creeks (figure 42). It has its greatest development in northeastern Cherokee and southeastern O'Brien counties, where Little Sioux

FIG. 42. View showing the rugged topography in the lower course of Brooke creek in northwestern Buena Vista county. This topography is typical of the lower courses of the larger tributaries of Little Sioux river. (Macbride, Iowa Geological Survey, volume XII, p. 315.)

river is 175 to 200 feet below the upland, and where many small tributaries have cut three to five miles into the upland, producing a much dissected area with a relief of 125 to 150 feet. The slopes are steep but the divides are level and project as spurs of the upland between the ravines out to the very edge of the Little Sioux valley.

East of southeastern O'Brien county the sharply dissected belt along the Little Sioux valley is narrower, and at many places the slightly rolling plain comes up to the very edge of the valley. Good examples of this condition are to be found on either side of the valley in the southwest corner of Clay county, in Gillett Grove township of eastern Clay county, opposite Sioux Rapids (figure 38), and elsewhere. Notably sharply dissected areas are present southeast of Cornell in Herdland township, in section 4 of the same township, in section 27 of Peterson township and at other places.

The area of sharply dissected topography along the Little Sioux valley is more extensive at the mouths of the tributary creeks, and extends up the larger of these creeks for a number of miles. It extends several miles up Willow creek valley in southcentral Clay county but with decreasing relief and ruggedness. It continues up Brooke creek valley (figure 42) in northwestern Buena Vista county for about four miles, and up other smaller creeks to the northwest of Brooke creek through the northcentral part of Brooke township. In southeastern O'Brien county where this sharply dissected topography is so well developed along the Little Sioux, it continues up Waterman creek valley for seven to eight miles, through central Grant township. The dissection here is remarkably sharp, giving a topography that is in striking contrast with the level upland to the east and west. The sharply dissected topography extends six to eight miles up Mill creek valley in Cherokee county and affects the lower courses of its tributaries.

If they are viewed from a distance, most of these tributaries of the Little Sioux appear to have broad shallow valleys, but as they are approached more closely what appeared to be broad shallow valleys are found to be trenched by narrow steep-sided valleys (figure 43). This feature is particularly prominent in

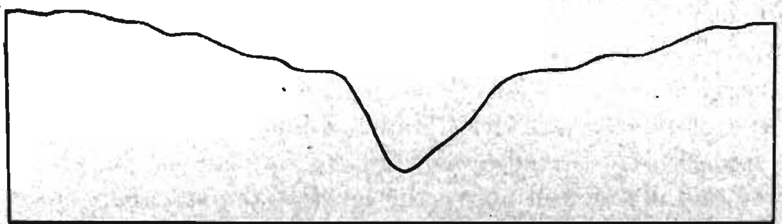


FIG. 43. Cross profile of a tributary valley of the Little Sioux showing the trenchlike inner valley cut into the broader outer valley.

the lower courses of the tributaries. Farther up these creeks, the narrow valleys in the bottoms of the older ones grow shallower until they terminate, and above their upper ends the streams flow through broad shallow valleys similar to the wider parts of the valleys farther down stream. The valley of a small creek which joins Mill creek in section 10 of Cherokee township and which is followed by the Illinois Central railway northward toward Larabee, shows well the passage from the sharply dissected topography to topography of the upland type. In its lower course the inner valley is sixty to seventy-five feet deep, but farther north it is shallower until at Larabee it is absent and farther northward the stream flows in a broad, shallow valley.

When the Ocheyedan-upper Little Sioux system was thrown southwestward across the great watershed into its present course (pages 310 to 318), new conditions were established and the great quantity of water carried by the Little Sioux soon deepened its valley notably, and destroyed the adjustment between it and its tributaries. The rejuvenated tributaries and the valley-side gullies then began to carve out the sharply dissected topography described above. It is all the work of post-Wisconsin time, and cutting in the tributary valleys is still in progress.

Gravel Hills.—At various places on the Kansan plain there are gravel hills or mounds hardly distinguishable from the usual features of the region. Some of them are in groups; some in rows along the upland valleys; and some are single isolated hills. In the northeast corner of Lyon county north and west of Little Rock there is a group of these hills which give a topography which appears to be constructional. Along the course of Willow creek leading west from Calumet in southern O'Brien county there is a row of them. These kamelike hills are more fully treated on pages 362 to 372.

Gravel Benches.—Gravel benches exist along many of the valleys of the Kansan drift-plain. Some of them are conspicuous topographic features, as they are continuous for great distances and stand well above the level of the streams; but some are merely inconspicuous remnants of terraces or shoulders on the valley sides. They are most prominent along the Little Sioux through Cherokee county and in the lower courses of Mill, Waterman and Brooke creeks. The dissection of the benches is as a rule much sharper than that of the uplands, being of the sharply dissected type of topography described above (pages 327 to 330). All the small creeks cross these gravel areas in narrow, steep-sided valleys while upstream on the upland they may have broad, open valleys. Even the smaller valleys generally have gravel deposits along their courses, even out near the heads of small streams on the upland. Benches may or may not be present, depending upon the extent to which the stream has cut into the valley filling. The valley gravels are discussed more fully in Chapter V.

Sand Hills North of the Spencer Flat.—At a number of places along the north side of the Spencer flat there is a topography characterized by low, rounded hills, with a relief of only ten to twenty feet. These hills appear at first sight to be glacial but a closer examination shows that they consist largely of sand, and that sandy roads are common in the belt where they are present. As noted on page 324 the poor drainage of the plain just north of Spencer apparently is due in part to obstruction caused by this low, ridgelike belt of hills.

This topography begins at the east end of the Spencer flat just west of Meadow brook, and extends westward as a low, slightly rolling ridge bordering the flat through the north half of section 9, the south half of section 5, and the central part of section 6 of Sioux township. It is present in section 1 of Riverton township and in the north half of section 36 and the northeast quarter of section 35 of Summit township where some shallow road-cuts show exposures of sand. The north half of section 32 and the adjoining parts of sections 29 and 30, Summit township, on the point of upland between the Little Sioux and Stony creek valleys, have a topography of slightly rolling hills with a relief of about ten feet, and the road on the north line of section 32 is quite sandy. Similar topography and sandy roads are found just north of Everly, and in section 33 and the southwest quarter of section 28 of Waterford township are rounded hills half a mile back from the valley which are said to be composed of sand. Farther northwest at the southeast corner of Osceola county, along the east bluff of the Ocheyedan river valley, there is another belt of low, rounded hills composed of sand, and similar features are shown faintly northwest for several miles across Harrison township.

The distribution of these sand areas to the north of the Spencer flat and to the northeast of the Ocheyedan valley accords with the usual location of eolian deposits on the northeast side of valleys, due to the prevailing southwest winds of our latitude. They probably were formed during the Wisconsin glacial epoch when Ocheyedan river was carrying great floods of debris-laden water from the margin of the Wisconsin ice-sheet.

All these areas of sand hills are along the course of the "Altamont moraine", as mapped by Professor Macbride in his discussion of "The Margin of the Wisconsin Drift"[42] (figure 28). They resemble a faint, glacial topography, and may have been so interpreted by Professor Macbride.

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[42]Iowa Geol. Survey, Vol. XII, pp. 329 and 333, 1901.

HISTORY OF THE KANSAN TOPOGRAPHY.

In the Kansan drift-region of southern Iowa the principal divides of a region commonly rise to a uniform altitude and have some level surface at their summits. These level areas are interpreted as remnants of the original Kansan drift-plain which is thought to have been relatively level, without marked constructional features.

These level uplands of southern Iowa are covered with fifteen to twenty feet of gray to dark colored, noncalcareous, sticky clay which Professor Kay has called gumbotil[43] and interpreted to be the result chiefly, of the chemical weathering of Kansan drift[43a] on the level Kansan drift-plain. After the development of the gumbotil zone uplift is believed to have occurred and erosion has carved out a mature topography and reduced most of the surface below the level of the former gumbotil plain. The above interpretation is based on the evidence of the few remnants.

Remnants of the gumbotil zone have been found northward to Carroll and Crawford counties, just south of our region.[44] The most northerly known outlier of the Kansan gumbotil is exposed in a railway cut east of Kiron, a few miles south of the southwest corner of Sac county.

Neither the level uplands nor the gumbotil have been found within our region although exposures of unleached till have been seen on most of the high areas. However, it is believed that northwestern Iowa has passed through essentially the same history as has been outlined for southern Iowa by Professor Kay. That is, that the Kansan ice-sheet left a relatively even drift-plain; that the gumbotil was developed over the entire region; that the gumbotil plain was uplifted; and that it has since been eroded. This erosion, however, has been greater in northwestern Iowa than in southern Iowa, so that, although remnants of the plain and the gumbotil remain in southern Iowa, in northwestern Iowa all the surface has been reduced below the level

[43]Kay, G. F., Gumbotil, a New Term in Pleistocene Geology: Science, Vol. 44, pp. 637-638. 1916. See also this volume. p. 217.

[43a]Kay. G. F., Bulletin of Geol. Society of America, Vol. 27, pp. 115-117, 1916. Also Iowa Geol. Survey, Vol. XXV, pp. 612-615, 1916.

[44]Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Surv., Vol. XXVI, pp. 213 to 231, 1917.

of the gumbotil plain and every remnant of the plain and the gumbotil has been destroyed.

Concerning this matter of erosion of the gumbotil plain in Carroll county just to the south of our area Professor Kay says:[45]

> The history of northern Carroll county and farther to the north seems to have differed from the history of the Templeton region (southern Carroll county) in having undergone still greater erosion. Northward from Templeton there are fewer and fewer remnants of the weathered zones until none are found. Moreover, in the region of Templeton there appears to have been more erosion than farther to the south. In southcentral Iowa the uneroded remnants of upland with gumbotil and leached drift are a somewhat distinctive feature of the topography.

The above explanation includes several points that have not been conclusively proved but the interpretation explains the conditions fairly well. It has not been proved that the gumbotil plain extended over northwestern Iowa. However, the writer has seen some of the evidence, in southern Iowa and in Carroll and Crawford counties just south of our region, upon which Professor Kay bases the gumbotil idea, and considers it so strong that he cannot fail to use this interpretation for the southern part of the region here under discussion. It is believed that the development of the gumbotil to a depth of fifteen to twenty feet over southern Iowa required a very great length of time. Such thicknesses are found northward to Carroll county where a section recorded by Professor Kay from a railway cut three miles west of Templeton shows twenty and one-half feet of Kansan gumbotil.[45a] It seems very probable therefore that the gumbotil was developed farther northward over northwestern Iowa during this same long interval of time.

The way in which the remnants of the gumbotil on the highest divides become fewer and smaller as they are traced northward in westcentral Iowa, and especially in Carroll county, indicates

[45]Iowa Geol. Surv., Vol. XXVI, p. 218, 1917.
[45a]Iowa Geol. Survey, Vol. XXVI, p. 220, 1917.

strongly that these remnants have been entirely destroyed farther north, that is that northwestern Iowa has been entirely reduced below the level of the gumbotil plain. The altitude of the remnants of the gumbotil along the divide between Mississippi and Missouri rivers increases northward from about 1250 feet at Tingley near the south line of the state to nearly 1500 feet west of Templeton in Carroll county. If these altitudes are used to project the plain northward, it is found that it would pass above all the high points.

An uplift of the region is postulated in order to cause the erosion of the gumbotil plain. In southern Iowa where remnants of the gumbotil plain exist the postulated uplift rests on firmer basis than for northwestern Iowa, where the uplift is merely inferred. The question as to why northwestern Iowa was eroded more deeply than southern Iowa in spite of the fact that it is farther up the Missouri valley, has not been satisfactorily answered. Possibly the uplift in northwestern Iowa was greater than in southern Iowa; possibly it occurred earlier. There exist in northwestern Iowa considerable areas of slight relief which must be interpreted as having been reduced below the original plain and yet they are not at flood plain level. The origin of these areas is not understood.

The Kansan Drift.

GENERAL CHARACTERISTICS.

The Kansan till of northwestern Iowa consists of a clay matrix with numerous sand grains, pebbles and bowlders scattered through it. The matrix is finely ground rock-flour, gritty from the presence of very small sand grains, but somewhat plastic if moderately moist. At the surface and in exposures of moderate depth the till is oxidized and has a yellow or brownish yellow color. Below this is the unoxidized "blue clay" phase of the Kansan. The till is cut by numerous joint planes belonging to sets that intersect at such angles as to give the clay a very characteristic fracture into angular fragments a quarter to three-quarters of an inch across. Both the oxidized and unoxidized phases are strongly calcareous even up to the surface or up to the base of the overlying loess. Calcareous material is present further in the form of small grains, pebbles and bowlderets of limestone, and near the surface at many places, as small concretions and as gray powdery material along joints.

At many places within the Kansan region, a drift somewhat lighter in color than the typical Kansan is to be found. It is yellowish gray or brownish gray instead of the usual brownish yellow. However, the difference is not distinct and it seems that there are all gradations. Commonly this lighter colored till contains considerable pebbly material scattered through it and has associated with it lenses and beds of gravel. This phase of the till is found in a number of exposures north of Cherokee, as in the bluffs of Mill creek in section 14; as a layer of till in the pit of the Cherokee Sand and Gravel Company; and in the northwest quarter of section 13, Cherokee township, on the farm of M. Doupe. North of Cherokee county, this phase is commonly present and is the usual till material. The difference is not one that would distinguish this as a separate till and it is apparently a fresh phase of the Kansan where it is associated with and contains much gravel.

The yellow clay at the surface and on the face of cuts is moderately loose, but a few inches beneath the surface it is compact and hard, and if wet is tough and gummy. The oxidized yellow clay horizon has an average thickness of twenty to thirty feet, with a range from zero to probably fifty feet. In general, it is thicker in those parts having a more rugged topography and thinner in the more level regions. It is thicker on the hills than in the valleys, and in some of the marshy flats it is entirely absent, and blue clay lies directly beneath the soil or alluvium.

Calcareous concretions one to two inches across exist in the upper part of the oxidized Kansan till in many of the exposures. They are not so large as those of the Nebraskan till but are larger than those commonly found in the loess. They are formed by the leaching of calcium carbonate from the till and its concentration in nodules lower down in the drift. At a number of places these nodules have an elongate form and stand in a vertical position along the joint planes. They are more numerous and larger in the Kansan till south of our region, as exposed in the cuts of the Chicago, Milwaukee and St. Paul railway in Carroll county.

In most exposures the blue clay is plastic and gummy, and if only recently exposed, is very tough and hard. When dry it has a light, blue-black or bluish gray color on the face of the exposure, while just beneath the surface it is almost black, and with greater depth grades into the typical blue clay. The blue clay is exposed in the banks or beds of many valleys where erosion is now active, and is penetrated by all wells of any great depth. Its thickness varies with the total thickness of the Kansan, of which it forms the larger part.

The blue clay is the fresh unoxidized phase of the Kansan till, and the yellow clay is the oxidized form. The transition from the blue to the yellow is as a rule abrupt or accomplished within a very thin transition zone, but the alteration to a yellow color may extend down into the blue clay along joint planes, affecting the clay for several inches from these planes. Where the till is much broken by intersecting joints and is mixed with irregular pockets and veins of sand which allow the weathering agents irregular access to the till, there is, at the contact, a zone several feet thick made up of masses of unaltered till enclosed in altered till. Where the till is moist, and where, because of recent erosion and exposure, rapid alteration is now in progress, a blue-black phase is present in the transition zone between the blue and brownish yellow phases.

Gray limestone is the dominant rock material among the pebbles of the Kansan till, forming more than 70 per cent of the total number of pebbles. Other types of limestones, and a few quartzites and shale pebbles increase the number of sedimentary pebbles to about 77 per cent of the whole. The remaining 23 per cent are igneous pebbles, chiefly granites. The large bowlderets and bowlders are dominantly igneous; quartzite, which is never abundant in the analyses of pebbles, is common while limestone bowlders are rare. The pebbles of the Kansan drift are in most cases rounded or subangular, but a few are angular. The drift separates cleanly from the pebbles, and the white limestone pebbles show plainly against the darker clay.

SOURCE OF MATERIAL FOR THE DRIFT.

The bedrock of northwestern Iowa belongs to the Cretaceous system which also is present in great thickness to the north. The dominant rock of this system is shale, and the remainder is largely shaly limestone and friable sandstone. Its most notable contribution to the drift was the material for the clay matrix, which was derived largely from the shale, but it also yielded much soft limestone which was ground to powder. Although they contributed the bulk of the drift material, the Cretaceous rocks are not common among the pebbles, and never appear among the bowlders.

The compact, gray limestone pebbles of the till are commonly unfossiliferous, but a few contain fragments of Ordovician fossils. No limestone of this age is known in the bedrock of northwestern Iowa or for several hundred miles to the north along the course followed by the ice, but in the northwest corner of Minnesota and extending northward along the valley of Red River of the North through Manitoba to Lake Winnipeg and beyond, there is a belt of Ordovician, Silurian and Devonian rocks which probably furnish the limestone pebbles of our region. The igneous pebbles and bowlders were derived from the pre-Cambrian rocks of Canada and northern Minnesota, and from the smaller areas in the Red river and Minnesota river valleys. The large amount of calcareous material in the matrix of the drift was derived in part from the impure limestone and calcareous shale of the Cretaceous, and in part from the Paleozoic formations that furnished the limestone pebbles.

In the extreme northwest corner of Iowa are a few outcrops of quartzite, and to the northwest around Sioux Falls, there are considerable areas of this rock. It is very resistant, and furnished many bowlders for the drift of northwestern Iowa. In decreasing abundance they occur southward to the limit of glaciation.

Preceding the Kansan epoch, northwestern Iowa had been glaciated by the Nebraskan ice-sheet, which deposited a thick sheet of till. As the Kansan ice-sheet advanced over the surface of the Nebraskan till, it gathered up great quantities of the older till and mixed it with such new materials as it brought in, making the Kansan drift. It also picked up masses of Nebraskan till and incorporated them in the Kansan till without intimate mixing. There are also masses of gravel, sand and silt inclosed in the Kansan, and these probably were gathered in a similar way either from interglacial deposits resting on the Nebraskan, or from outwash deposits laid down in front of the advancing Kansan ice-sheet. These gravel masses and the evidence as to their age are considered on pages 357 to 361.

EXPLANATION OF THE FRESHNESS OF THE TILL.

A notable character of the Kansan till of northwestern Iowa is the small amount of alteration and weathering which it shows. Oxidation to a yellow color commonly extends to a depth of twenty to thirty feet, and locally the till is iron-stained along the joints, but the degree of this oxidation is only moderate. Excessive oxidation of the type represented by the iron-stained horizon (ferretto) present at the top of the Kansan till at many places farther south, is lacking in northwestern Iowa. Further, the Kansan till of northwestern Iowa is commonly calcareous to the surface. In only a few places, in the south and southwest part of the region, was any leached till found. Even where the overlying loess is leached for its entire thickness, the till beneath is unleached.

In southern Iowa leached till is much more commonly present and in many places has a depth of several feet. It occurs in a zone which directly underlies the gumbotil of the remnants of the upland, where it may be seven to ten feet thick. In such position it grades upward into the gumbotil and represents a less altered phase of the till.

If a gumbotil zone was formed over the Kansan drift-plain of northwestern Iowa, there was formed also beneath it a zone of leached till, but the erosion which removed every vestige of the gumbotil (page 332) also removed the leached zone of Kansan till beneath, exposing unleached till everywhere at the surface. This complete erosion of northwestern Iowa below the original plain explains the absence of leached till.

The Loess.

GENERAL CHARACTERISTICS AND DISTRIBUTION.

The Kansan drift of northwestern Iowa is covered with a mantle of fine-grained, yellow clay known as loess. In the southwestern part of the area the loess has a considerable thickness, but it thins to the northeast until it is almost negligible. In the regions where the loess is thick, it is commonly calcareous to the surface and in many exposures contains calcareous concretions and snail shells. Farther northeast where the surface is more even and the loess is thinner, it is leached in its upper part, and shells and calcareous concretions are absent.

The region within which a well developed loess covering exists includes Woodbury county, Ida county (except the northeast part), the southwest part of Sac county, and a belt along the east side of the Big Sioux valley narrowing northward through western Plymouth, Sioux and Lyon counties. Within this area many road-cuts on the slopes or on the crests of the hills expose ten to twenty feet of loess and commonly it is calcareous to the surface.

A particularly rugged belt five to ten miles wide just east of the Missouri river valley in Woodbury and southwestern Plymouth counties has a thick deposit of loess in which exposures of thirty to fifty feet or more exist. It is an area of distinctively loess-formed topography which continues southward along Missouri river across western Iowa (figure 41, page 327).

The loess is much thinner within a short distance to the northeast so that there appears to be a loess-boundary. This belt within which the loess becomes so much thinner leaves the Wisconsin drift-boundary near the south line of Sac county and extends northwest across southwestern Sac, northeastern Ida, southwestern Cherokee and southeastern Plymouth counties. West of the Floyd river valley it extends west of north through western Plymouth, Sioux and Lyon counties. The change is more abrupt in Sac and Ida counties than farther northwest and more abrupt where this belt follows valleys than where it crosses upland country. In some places it seems to be a definite boundary but on the whole it is simply a zone within which the thinning of the loess is very marked.

The zone within which the loess thins so notably is quite definite south of Wall Lake in Sac county through sections 33, 32 and 30 of Viola township and sections 25 and 24 of Levey township. To the southwest is a rough topography with a relief of fifty to a hundred feet and road-cuts at the crests of the hills show ten feet or more of loess. To the northeast the region is not so rugged, the relief is less and the mantle of loess is only a few feet thick. A marked contrast exists along a small valley through sections 33 and 32 of Clinton township northwest of Wall Lake. In section 32 on the southwest of this valley the topography is rugged with a relief of seventy-five to a hundred feet, with very steep slopes and sharp crests and the road-cuts through these crests expose fifteen to twenty feet of loess without reaching its base. Across the valley in section 33, the general altitude is thirty to fifty feet lower, the surface is moderately rolling and loess is not prominent. A similar contrast exists along the Boyer valley in sections 34 of Clinton and 2 of Levey townships. This latter case is directly east of the former and shows a repetition in an east-west line of the contrasting, opposite sides of the valleys.

Northwest of Odebolt toward Maple river there are several places where the border of the thicker loess is definite but it is not a continuous boundary. The loess is thickest on the higher points and there is commonly some group of hills or a divide where the thicker loess projects farther northeast than is general and along the northeast base of these hills the marked change is located. The first course of this type northwest of Odebolt is along the northeast base of a belt of hills in sections 21, 20 and 18. In section 18 this belt is cut across by a tributary of Odebolt creek but on the west the loess-covered hills continue through Blain township as the divide between Odebolt and Elk creeks. Loess-covered hills, however, exist north of Elk creek along the divide separating it from Buffalo creek in southern Silver Creek township, in section 26 on the headwaters of Buffalo and Elk creeks and in southeastern Logan township in the angle between Buffalo creek and Maple river. In the two latter places very marked contrasts exist for short distances.

A very marked contrast exists along the course of Maple river valley from section 25 of Logan township north to section 22 of Galva township. Rugged topography with deep loess cuts exists to the west of the valley while to the east it is less rugged and there are few exposures of loess.

Northwest of Maple river the loess thins more gradually, but at a number of places along the north-south valleys more rugged topography exists on the west slope than on the east. This feature is present in the case of several of the parallel valleys and is not a characteristic simply of the belt within which the loess becomes thinner but of the region of thick loess. This feature is shown along the West Floyd and other valleys of westcentral Plymouth county.

In the region farther northeast the loess exists as a thinner mantle commonly three to six feet in thickness. The slopes are gentle and exposures are few and shallow. Here the loess is leached in its upper part and at many places for its entire thickness where this is less than five feet. Where the loess is thicker than four to five feet, the basal part is unleached. The underlying till is commonly unleached even where the loess is entirely leached, which indicates that the leaching of the till takes place much more slowly than the leaching of the loess. The contact of the loess and the till is commonly definite even though the till surface has slight irregularities into which the loess fits.

This area within which the loess has a moderate thickness includes northwestern Sac, western Buena Vista, Cherokee, O'Brien and Osceola counties, outside the Wisconsin drift-boundary, and most of Sioux and Lyon counties. Most of this region has only a moderate relief and exposures are few.The natural exposures, being on the lower slopes of the valleys, do not commonly show the loess, which has been removed from such positions, and one must depend largely on artificial exposures on the level surfaces for data as to its thickness. Such exposures were found at Wall Lake, Odebolt, Arthur, Early, Schaller, Galva, Storm Lake, Alta, Cherokee, Primghar, Sheldon, Sibley, Little Rock and George (pages 349 to 356).

In Clay and southern Dickinson counties the loess is only two to three feet thick and the surface is very level. When it is less than two and one-half feet thick this mantle is commonly not definite loess but a loesslike clay which may contain sand grains and pebbles throughout. When traced from the southwest it is very evident that this is the continuation of the loess mantle.

TOPOGRAPHIC INFLUENCE OF THE LOESS.

The topography of the Kansan region is a loess-mantled topography. The influence of this mantle differs from place to place with the thickness of the loess and the nature of the topography at the time the loess was deposited. In the rugged belt east of Missouri river in Woodbury and southwestern Plymouth counties, the thick deposit of loess of the hill tops has been a dominant factor in the production of this topography. The topography in its character and its relief is, in part loess-formed. Throughout the remainder of the rugged region the loess is thickest on the hill tops, which results in a slight increase in the relief of the region.

Over the major part of our region the preloess topography was rolling or slightly rolling with a relief of thirty to sixty feet. The loess accumulated to a thickness of five to fifteen feet and made a somewhat uneven veneer which resulted in the formation of faint constructional features on the slopes of the major erosional features. It is in this region that the loess produced probably the greatest changes. Its effect was, in general, to make the slopes more gentle and in some places it entirely effaced small irregularities by filling in small valleys (page 352).

Far to the northeast where the surface was very even and the loess mantle deposited was thin, the topographic effect was slight, although here the effect was to make the surface more even by the filling of small irregularities.

THE LOESS OF THE KANSAN REGION.

The very definite and characteristic loess of the southwestern counties of our area has been recognized as loess from the earliest geologic work done in the region. This includes the area noted above (page 339) as having a thick covering of loess. The deposit that overlies much of the Kansan region to the northeast and which is commonly leached for its entire thickness has not previously been recognized as loess. It was called loesslike clay or loam by the writer through much of the progress of the work and its identity with the loess to the southwest was not demonstrated until the summer of 1916. Previous to this time there had been considerable question as to whether the whole of this region should be included in the Kansan.

The extremes included within the Kansan region are very different. In the region of thicker loess, the yellow calcareous concretion bearing fossiliferous loess is seen at many places. In the region of thinner loess, there are few exposures and these show the noncalcareous brownish yellow pebbleless loesslike clay. But within the region of positive loess there are exposures in which the upper part of the loess is leached and certain level areas where the leached loess is general, and in these places the leached loess is identical with the loesslike clay (leached loess) farther northeast. Scores of exposures were studied by the writer as he passed back and forth from the region of thick loess to that of thin loess and in this way the identity of the loess of the entire region was established. The loesslike clay of the thinly mantled areas is identical in origin with the distinctive loess of more deeply covered areas.

PEBBLES WITHIN AND ON THE SURFACE OF THE LOESS.

In the region of thin loess and to a large extent elsewhere a few pebbles may be found within the loess, especially in its basal part. Their distribution is of two types: (1) pebble bands bedded in the loess, and (2) occasional pebbles scattered through the loess. Those of the first class are restricted to the basal twelve to eighteen inches of the deposit and are found where the loess overlies gravel in the valleys, or on the lower slopes of the hills, where the loess accumulated on a topography of some relief. In the case of the occasional pebbles scattered through the loess they are found in large part where the entire thickness of the loess is not more than three feet. It was found that many of these pebbles could be shown to occupy old burrows of animals, and in many cases where the burrow was not at first apparent a careful examination revealed it. Not every pebble found in the loess was proved to be in a burrow but a large percentage of them was found to be so located and probably practically all have had such an origin. The burrows go from four to six feet beneath the surface and at some places are quite numerous. In some cases where the burrows passed through the loess into gravel below, the burrows appeared like tubes of pebbles in the loess. Where the loess is more than four feet thick few of the burrows go through the loess and there is no opportunity for obtaining the pebbles.

In almost any part of the loess-covered area it is possible to find a few pebbles on the surface or in the loess soil. They may be found along the public roads and less frequently in the fields. Careful search along the road enabled the writer to find one or more pebbles along practically every quarter of a mile of road where the search was made within the loess area. There are several ways by which these pebbles may have come to their present location. Where the loess is thin they may be brought up by burrowing animals from the drift beneath the loess. Many of the pebbles along the roads have dropped from the loads of gravel being hauled along these roads. The pebbles in the fields may come with manure hauled from barn lots, most of which have gravel in them. Others may have been carried from neighboring valleys in the mud attached to wheels, or to the feet of animals of historic or prehistoric times. It may be noted that during a search for pebbles, especially along the roads, one also finds nails, pieces of coal, cinders, iron, glass and crockery, bottle caps, bases of shot gun shells, etc. All these things have come to their present location by accident and were not derived from the loess beneath and likewise the few pebbles are believed to have come by accident to their position on the surface of the loess and not from within the loess.

Over much of the Kansan region the loess does not completely cover the surface but exists where conditions were favorable for accumulation or where erosion has been slight. The mantle of loess completely conceals the till where the surface is level or only slightly rolling, but on steep slopes the till is commonly exposed because erosion has removed the loess. The east and north slopes of hills have a thicker loess mantle than the opposite slopes or the crests of the hills, which is explained by the prevailing west and southwest winds and by the greater accumulation of the loess in the lee of the hills. Till is exposed at the crests or on the upper slopes of many hills which farther down the slopes have a complete loess covering. Under these conditions pebbles from the drift near the crest of the hill are washed down the slope onto the loess. Many examples of this condition were observed, where in ascending a loess-covered slope occasional pebbles were found and at the top of the slope the drift is exposed. It is not possible in all cases to show that the loess is above the till, but it is possible to do this at many places. An example of this is to be found west of Le Mars in Plymouth county west of West Floyd river on the south line of section 12, Washington township. Cuts in the lower slope show six to eight feet of loess without exposing the till but occasional pebbles are found on the road and in the gutters. Toward the crest of the hill just west of the southwest corner of section 12 the loess thins out and the till rises to the surface.

An excellent exposure showing the relation of the till and loess exists in a road-cut about fifty yards north of the southwest corner of the section 12 noted above. The cut extends from north to south, and is at the crest of a slope leading down to a valley to the north. The road grade ascends the slope and cuts the crest. At the crest of the hill the Kansan till rises five feet above the base of the cut and is overlain by six feet of brownish pebbly leached material (figure 44). In either direction from the crest the upper contact of the Kansan dips steeply and passes below the road grade, and the brownish leached zone thins to one foot and becomes an old soil. There is no true loess in the section at the crest of the hill, but below the crest in either direction it is present above the leached ma-

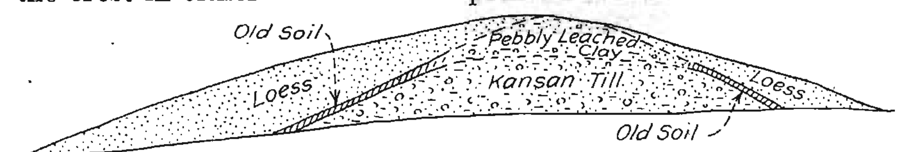


FIG. 44. Sketch of a road-cut exposure fifty yards north of the southwest corner of section 12, Washington township, Plymouth county.

terial and it thickens notably down the slopes, especially on the north slope where it attains a thickness of at least ten feet. Pebbles may be found lying on the loess on the natural slope of the hill and no doubt they were washed down from the leached pebbly material exposed at the crest of the hill. If this were a shallow cut it would be like scores of others which were seen but in which the source of the pebbles was not so evident.

The most indefinite part of the loess mantle is commonly found near the crests of the hills where the mantle is thin. It cannot in all cases be so definitely related to the till as in the exposure just described, for if the cut is shallow, the relation of this material to the loess is not evident and it may appear to be above the loess which covers the slope lower down. In all cases, however, where an adequate cut exists it is evident that the sandy, pebbly material passes below the loess or grades laterally into it. In no place does it overlie the loess. This material at the crests may be distinctly different from the loess, as in the cut described above, or it may differ from the loess only in the presence of a few pebbles. In the former case it has been derived in part from the till while in the latter case the bringing in of a few pebbles by burrowing animals or other means would suffice to explain the difference.

The description of some cuts along the road leading east from Cherokee will illustrate these relations. The north side of the road-cut about half way up the east slope of the Little Sioux valley exposed the following section, which is shown diagrammatically in figure 45 while a view of it is given in figure 46.

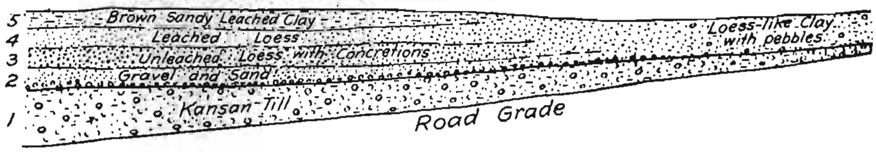


FIG. 45. Sketch of exposure showing the thinning of the loess toward the crest of a slope, and its passage into an indefinite pebbly loesslike clay. The exposure is in a road-cut in the east slope of the Little Sioux valley east of Cherokee. A view of a part of this exposure is given in figure 46.

		FEET.
5.	Slightly sandy dark material, including the soil......	2
4.	Leached loess	3
	In part of exposure it is very dry and hard and breaks out in blocklike chunks.	

3.	Ashy gray calcareous loesslike clay with concretions and containing some thin beds of sand at the base....	2½
2.	Sand and fine gravel with a few bowlders at the base.	2½
1.	Dark brown Kansan till, exposed....................	8

Number 5 of this section is slope wash material to which is added probably some sand blown up from the valley bench which is present lower down on the slope. Farther up the slope all horizons above the Kansan are thinner and numbers 3 and 5 pinch out entirely (figure 46). Near the crest the combined

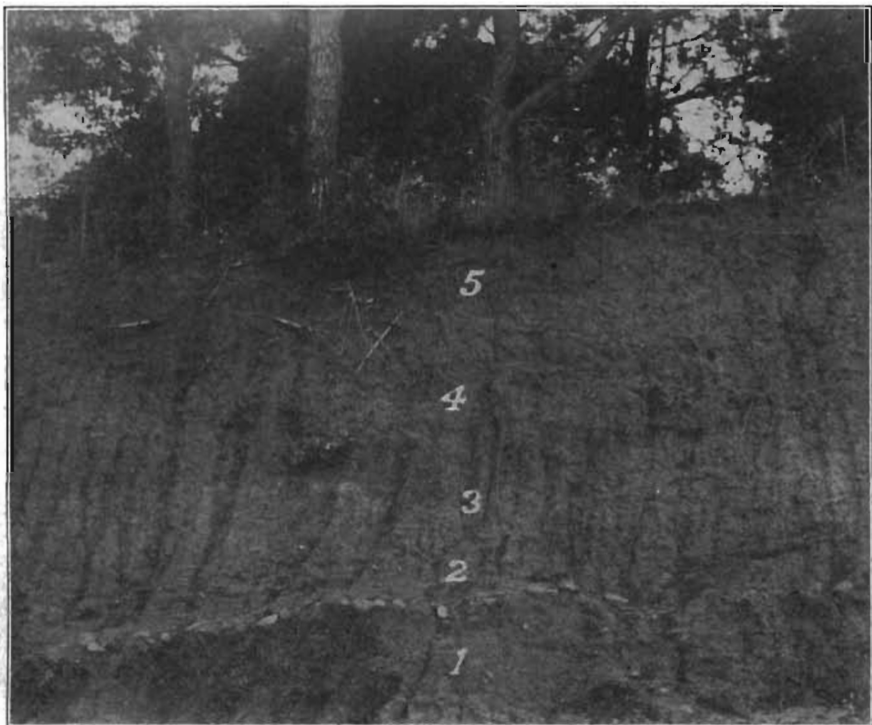


FIG. 46. View of the north side of the road-cut about half way up the east slope of the Little Sioux valley east of Cherokee. Zone number 1 is Kansan till; number 2 is gravel and sand; number 3 is unleached loess with concretions; number 4 is leached loess; number 5 is brown sandy leached clay. The zones of this exposure are shown diagrammatically in the left part of figure 45. (Photo by Kay.)

thickness of all the material above the till is only three or four feet. In this part there are a few pebbles distributed through this loesslike clay zone and at one place on the slope a layer of pebbles exists in its lower part. If this material which is exposed at the crest of the slope were all that was present on the hill it would not be interpreted as loess, and yet it passes laterally into the more definite loess zone.

East of the crest of the valley slope the leached loess is exposed in the shallow cuts of the upland. If the loess zone is three and one-half to four feet thick it may show a thin zone of unleached loess at the base. Unleached Kansan till with small calcareous concretions underlies the loess. On the south side of the road just east of the first ravine east of the schoolhouse on the south line of section 25, is an exposure a sketch of which is shown in figure 47. The east slope of the low hill has a

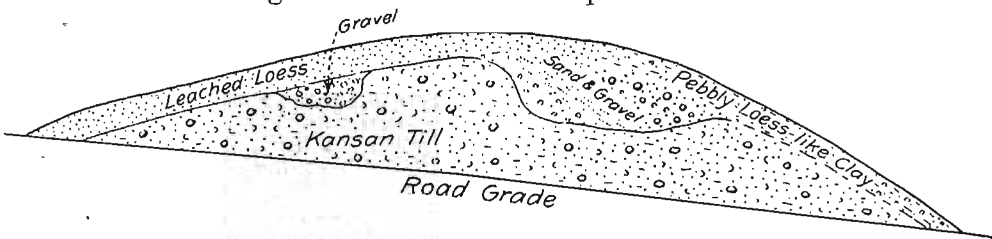


FIG. 47. Sketch of an exposure showing the relation of loess and loesslike clay to the underlying till and gravel mass. Exposure on south side of road in cut just east of the first ravine east of the schoolhouse on the south line of section 25, Cherokee township, Cherokee county.

mantle of about three feet of leached loess resting directly on the unleached Kansan till, which contains calcareous concretions. In the central part of the exposure are several gravel masses inclosed in the till and overlain by the loess. These are included gravel masses in the Kansan till which were exposed at the surface at the time the mantle of loess was formed. The west slope of the hill is steeper because it is on the slope of a small valley, and on this slope the loess mantle is thinner and contains a few pebbles. This material on the west slope has been reworked by slumping down the slope.

East of this locality, along the south line of section 25 and 30, there are a number of cuts which expose four to six feet of loess, and in at least two cases about a foot of unleached loess containing concretions is present beneath the leached material. The first cut east of the southwest corner of section 30 shows at the center Kansan till overlain by two to three feet of dark loess-like clay which contains some pebbles. In either direction this material is thicker and grades into typical loess without pebbles.

DATA CONCERNING THE NATURE AND THICKNESS OF THE LOESS.

A great number of exposures showing the loess were studied and a few of the better sections, most of which are artificial exposures, will be recorded.

From Wall Lake west across Southern Sac and Ida Counties.—At the town of Wall Lake in southern Sac county, a basement excavation just north of the water tank showed the following:

		FEET.
2.	Leached loess, including the soil	5
1.	Unleached loess with a few concretions and some fine sand in thin seams at the base	3

Wall Lake is less than two miles from the Wisconsin boundary, yet this material is unquestionably loess.

At the town of Odebolt, in southwestern Sac county, a basement excavation in the southwest part of town exposed the following:

		FEET.
3.	Leached loess, including the soil	5
2.	Unleached loess	1½
1.	Yellow-brown Kansan till, exposed	1

Another excavation one square farther south showed:

		FEET.
2.	Leached loess, with the soil	4
1.	Yellow-brown Kansan till	2

A trench on the main street in the east part of town exposed:

		FEET.
2.	Leached loess	3
1.	Yellow sand with pebbles, exposed	6

The trench exposure was open for 150 feet and showed no changes laterally.

At Arthur, in eastern Ida county, a basement excavation in the north part of town showed four and one-half feet of leached loess to the base of the opening. This place is within the region of unquestioned Kansan drift and loess, yet this leached loess is identical with that found farther east at Odebolt and Wall Lake. The loess thickens to the west across southern Ida and Woodbury counties and is commonly exposed in the road-cuts. In many of the exposures the unleached concretion-bearing loess comes to the surface.

Five and a half miles south of Odebolt near the quarter corner on the west of section 26, Wheeler township, a gravel pit in Porter creek valley showed the following:

		FEET.
3.	Leached loess	5
2.	Sand with seams of loesslike clay	3½
1.	Fresh, clean gravel	14

In another part of the exposure the loess is seven feet thick and is leached to a depth of only two feet. This is typical calcareous loess containing concretions and a few small snail shells. This valley extends southward to Boyer river at Boyer in Crawford county, and in its lower course, gravel material overlain by fossil-bearing calcareous loess is exposed in several railway and other cuts.

From Early west across Northern Sac and Ida Counties.—At Early in west-central Sac county an excavation at the schoolhouse in the northwest part of town showed the following:

		FEET.
2.	Leached loess	3
1.	Unleached yellow Kansan till, exposed	4

Early is less than two miles from the Wisconsin boundary, and exposures along the road leading north from Early show that the leached loess, about three feet thick, continues to the edge of the Wisconsin drift.

About five miles northwest of Early a railway cut at the southwest corner of section 28, Eden township, showed the following:

		FEET.
3.	Leached loess	3½
2.	Unleached loess	½
1.	Typical Kansan till with concretions, exposed	6

At Schaller in northwestern Sac county the following section was measured:

		FEET.
4.	Leached loess, including the soil	3½
3.	Unleached loess	½
2.	Sand	½
1.	Unleached yellow-brown Kansan till, exposed	2

At Galva in northeastern Ida county a trench in the road in the south part of town showed the following:

		FEET.
4.	Leached loess	6
3.	Unleached loess	1
2.	Sand with cobbles	2
1.	Unleached yellow-brown Kansan till, exposed	1

Another exposure in the east part of town showed leached loess to the bottom of a trench four feet deep.

West of the Maple valley at Galva is the unquestioned loess region and the unleached loess is exposed in many road-cuts, as in the northwest quarter of section 27, Galva township, where it has a thickness of at least ten feet.

At Holstein in northcentral Ida county a trench exposure on the street showed the following:

		FEET.
4.	Leached loess, including the black soil at top	4½
3.	Unleached yellow-brown, mottled loess with a few concretions	4½
2.	Seam of sand	¼
1.	Unleached yellow Kansan till, exposed	2

The divide cut on the railway one mile east of Holstein exposed the following:

		FEET.
3.	Leached loess	4
2.	Unleached loess	2
1.	Yellow Kansan till with concretions, exposed	3

This series of exposures from Early through Schaller and Galva to Holstein extends from the Wisconsin boundary well within the unquestioned loess-covered Kansan. The loess is thicker to the west, as is shown by the increase from three feet at Early to nine feet at Holstein, and with this increased thickness the unleached zone appears, but the leached loess is the same at all places. Within a short distance west of Holstein the country is rugged and loess exposures are common in the road-cuts. A series of good exposures of loess existed in 1916 along the road paralleling the railway on the south from Cushing to Correctionville. The loess is thicker to the west across Woodbury county to Sioux City, where loess exposures thirty to fifty feet deep may be seen.

From Storm Lake west across Buena Vista, Cherokee and Plymouth Counties.—At Storm Lake a basement excavation on the main street showed the following:

		FEET.
4.	Soil	2
3.	Leached loess	2
2.	Unleached loess	1
1.	Unleached Kansan till, exposed	2

This exposure is within one mile of the Wisconsin boundary and in other exposures in the east part of town the loess may be found to and possibly beneath the Wisconsin drift.

At Alta excavations along the railway just west of the station and in the divide cut in the west part of town showed three feet of leached loess with soil, overlying unleached yellow Kansan till with some concretions. This is at the crest of the great divide.

In southwestern Buena Vista county, in the southwest quarter of section 21, Maple River township, on the farm of Will Litzenburger, a well boring passed through five feet of loess, and at the time of the writer's visit the well had been sunk to a depth of fifty feet, all in yellow Kansan till. This is an exceptional thickness for the oxidized zone of the Kansan till.

At Cherokee, at the new hospital in the north part of town, about fifty yards northwest of the building, a trench showed the following:

		FEET.
4.	Soil	2
3.	Leached loess	2½
2.	Unleached loess with a few concretions and containing thin layers of fine sand at base	1
1.	Sand with pebbles	2

This exposure is on the high gravel bench of the Little Sioux valley about 125 feet above the river. The position of the loess over the sand and gravel of the bench area shows that the gravel deposit of the high benches is older than the loess. A cut on Spruce street in the north part of town just east of Second street shows three feet of loesslike material overlying the gravel. The upper two feet of the zone is leached.

In 1916 a road in the northeast part of section 28, Cherokee township, had been recently graded and showed a number of good sections. The first cut north of the Cherokee water tank showed the following:

		FEET.
4.	Leached loess, including the soil	4
3.	Unleached loess	2
2.	Sand and pebble layer	⅓
1.	Yellow-brown Kansan till with concretions, exposed	2

The third cut north of the tower, located at a bend of the road (telephone pole 1554), showed the following:

		FEET.
5.	Leached loess, including soil	4½
4.	Unleached loess	1½
3.	Sandy loess	1½
2.	Pebble and sand layer	½
1.	Yellow-brown Kansan till with included gravel masses	2

In the loess zone of this exposure a section of a small elephant tusk about six inches long was found. Other cuts northwest to the viaduct across the spur of the railway show similar exposures. The first road-cut east of this viaduct showed:

		Feet.
3.	Leached loess	6
2.	Unleached loess	2
1.	Fine-grained clayey, sandy material	2

A railway spur in the southeast quarter of section 21 and the north part of section 28, on the grounds of the Cherokee State Asylum, showed in 1916 some newly made cuts. At the edge of the creek valley in the southeast quarter of section 21 the cuts show thirty feet of typical brownish yellow Kansan till with large included sand and gravel masses. A thin zone of leached loess exists at the top of the cut.

The largest cut along this spur is at and just south of the north line of section 28. The Kansan till rises fifteen to twenty feet in the cut and has included in it as lenses much material that is not typical Kansan. One section which was exposed by cleaning the face of the cut measured as follows:

		Feet.
9.	Leached loess, including the soil	6
8.	Unleached loess	2
7.	Alternating layers of loess and fine sand	4
6.	Pebble layer	1/6
5.	Unleached yellow Kansan till with concretions	3
4.	Unleached blue-gray pebbly till with a few concretions	2
3.	Noncalcareous dark brown pebbleless clay	3½
2.	Blue-gray till similar to No. 4	2½
1.	Yellow Kansan till, exposed	2½

All the material below the pebble layer (No. 6) is considered Kansan drift, numbers 4, 3 and 2, which are not typical Kansan, being interpreted as included material. It appears that the noncalcareous brown clay (No. 3) is material gathered up from some surface by the Kansan ice-sheet. The marginal parts of this mass became mixed with the Kansan till and form horizons 4 and 2 above and below it. The oxidized zone of the typical Kansan extends below the base of the cut (No. 1). Just south of the section line in this cut there are several masses of Nebraskan till included in the Kansan. One of these, an elongate lens, is more than fifty yards long and six to eight feet thick and is somewhat mixed with yellow Kansan till. Another smaller mass also consists of noncalcareous Nebraskan till.

The upper contact of the Kansan till in this cut shows a buried relief **not** expressed in the present topography; that is the small irregularities in the Kansan surface were filled in and obliterated by the loess.

Near the south end of this large cut, where the Kansan till has passed below the grade, the following section was measured:

		Feet.
3.	Leached loess, including the soil	6
2.	Unleached loess	3
1.	Alternating layers of loess and fine sand	4

A small cut at the level of the upland just northwest of the Institute buildings showed:

		Feet.
3.	Leached loess with soil	4½
2..	Unleached loess	1
1.	Kansan till	2

This illustrates the usual thinning of the loess on the hill tops as compared with the east or north slopes.

About a mile southwest of Cherokee, in the north part of the southeast quarter of section 33, on the north slope of a ravine valley, are some abandoned clay pits which show the following section:

		FEET.
4.	Leached loess, including the soil	5
3.	Unleached loess containing a few concretions	15
2.	Sandy, silty loess with a few layers of fine sand	5
1.	Slumped to bottom of pit	10

The material in the lower part of the exposure (No. 2) has a faint horizontal banding and may be partly waterlaid. It grades upward into the more typical loess, which here has an exceptional thickness for this region. The unleached loess (No. 3) is filled with the brown threadlike rootlet impressions which are characteristic of the loess. The top zone of leached loess is the same as that which is found in most road-cuts. This mass is below the general level of the country and its great thickness may be due to accumulation in the lee of the upland to the west. The deposit was formerly used for the manufacture of brick and tile.

Western Cherokee and eastern Plymouth counties have a loess mantle of sufficient thickness to conceal the till on all but the steeper slopes. The shallow road-cuts show dark soil passing into the leached loesslike clay below. Some cuts of four feet or more in the loess show the unleached phase. An exposure just south of the northwest corner of section 29, Sheridan township, Cherokee county, showed the usual horizons:

		FEET.
4.	Leached loess	3½
3.	Unleached loess	2
2.	Fine yellow sand	1½
1.	Yellow Kansan till, exposed	1

On the west side of the West Fork of Little Sioux river in the south part of section 23, Amherst township, a gravel pit showed the following section, which includes the horizons commonly existing along the valleys:

		FEET.
5.	Leached loess	3
4.	Unleached loess with pebbles in basal 6 inches	1
3.	Sand with a few pebbles and becoming more clayey above	4
2.	Medium-grained gravel with a few cobbles	5
1.	Fresh yellow Kansan till, exposed	2

Similar conditions continue for several miles west of LeMars, but within the more rugged country the loess is thicker and the unleached concretion-bearing phase is at the surface.

O'Brien and Sioux Counties—At Sutherland in southeastern O'Brien county, at the southwest corner of town, a post auger hole was bored through soil and leached loess to a depth of three feet and eight inches without reaching the base of the loess. In the east part of town are several pits in the gravel deposit along the headwaters of Murry creek that show three and a half feet of leached loess overlying the gravel.

Road-cuts in northern Cherokee and O'Brien counties show the black soil, which at a depth of twelve to eighteen inches grades into the yellow leached loess. If the exposure is over three feet deep the unleached Kansan till is commonly shown. A good series of road-cuts was exposed in 1916 along the township line road leading south from Primghar. One of these road-cuts in the southwest quarter of section 7, Highland township, showed three and a half feet of loess overlying till.

About half a mile north of the Sheldon railway station in a cut on the Chicago, Minneapolis, St. Paul and Omaha railway, the following section was measured:

		FEET.
4.	Soil	2
3.	Leached loess	1½
2.	Unleached loess	2½
1.	Till with calcareous concretions, exposed	1

Farther north near the crossing of Floyd river, abandoned gravel pits show a zone of leached loess three to five feet thick overlying the gravel. The base of the loess here contains a few pebbles (page 393).

In Sioux county, Sheridan township, at the southwest corner of section 29, an excavation for a storm cave in the schoolhouse yard showed eight feet of loess, the larger part of which is leached. Below the loess is a thin layer of sand and pebbles and then the unleached Kansan till. Two miles north at the southeast corner of section 18, in the schoolhouse yard, material thrown from an excavation for a storm cave showed that the loess has a similar depth, for the till was not reached. At the northeast corner of section 32, Lincoln township, an excavation for a cistern showed ten feet of loess without reaching its base. Careful search on the walls of the cistern and of the material thrown out did not show a single pebble.

Farther west in Sioux county, loess exposures are numerous but commonly show only the leached loess, except in the more rugged region near Big Sioux river where unleached concretion-bearing loess is found.

Clay and Dickinson Counties.—In Clay county, Douglas township, near the quarter corner on the south of section 25. an open trench showed the following:

		FEET.
4.	Soil	1
3.	Leached loess	1
2.	Unleached loess with a few concretions	½
1.	Typical Kansan till with a few concretions, exposed	2

This exposure is just half a mile west of the north-south center line of Clay county, and within four miles of the Wisconsin boundary across the Little Sioux valley, but the loess zone, although thin, is sufficiently well developed to be definitely recognized. To the north in central Clay county, towards Spencer, the loess horizon is thinner and in some places where it is less than two feet thick, it is not a definite loess zone. It forms, however, a thin mantle of dark to yellow clay commonly concealing the till and when it is traced from the counties to the west it is seen to be very definitely the equivalent of the loess. This is the condition over northern Clay and southwestern Dickinson counties outside the Wisconsin boundary.

Osceola and Lyon Counties.—In southeastern Osceola county, Harrison township, on the south line of the southwest quarter of section 2, a post auger hole gave the following section:

		FEET.
3.	Soil	1½
2.	Leached loess	2
1.	Kansan till	

On the west line of section 3. Harrison township, an open trench showed the following:

		FEET.
3.	Soil	1
2.	Unleached loess with concretions and iron tubules	1½
1.	Kansan till, exposed	3

On the north line of the northwest quarter of section 28. Ocheyedan township, a post auger hole gave the following section:

		FEET.
3.	Soil	1½
2.	Unleached loess with concretions	1½
1.	Pebble zone	

All three of these sections are within one mile of the Wisconsin drift-boundary.

Road-cut exposures in southern Osceola county commonly show the leached loess, which has a thickness of two and one-half feet and rests directly on the unleached Kansan till.

At Sibley, a trench just east of the intersection of the main streets showed the following section:

		FEET.
4.	Fill, chiefly of black soil	2
3.	Dark, peaty soil, passing into leached loess	2½
2.	Unleached loess with concretions and dark rootlike threads through it	1
1.	Typical brownish yellow Kansan till, exposed	1

This trench was open from the intersection of the main streets south for two blocks to the Rock Island railway and the loess was essentially the same all the way. At the first street crossing (near Windsor Hotel) gravel appears below the loess and is thicker to the south until the till drops below the bottom of the trench. The gravel was said to be five feet thick near the railway. An open trench east of the park in the northeast part of town showed similar relations of the loess, till and gravel (page 386, figure 44), and the gravel of the pits in the east part of Sibley is overlain by three to four feet of leached loess.

At Little Rock in northeastern Lyon county, a cellar excavation in the west part of town showed the following:

		FEET.
4.	Soil, passing to yellow clay at base	1½
3.	Leached loess	1
2.	Pebble band	¼
1.	Unleached yellow Kansan till, with small calcareous concretions near the top, exposed	6

Other exposures in the region show two and a half to three feet of leached loess, as near the southeast corner of section 35, at the northeast corner of section 22, and near the southeast corner of section 18, all in Elgin township. Farther west, in Lyon county, the leached loess may be seen in many exposures, and near the Big Sioux the unleached loess with concretions is commonly exposed.

Southern Nobles County, Minnesota.—The study of the loesslike clay was continued about ten miles north of the state line to Adrian in Nobles county, Minnesota. At the southwest corner of section 28, Ransom township, less than two miles from the Wisconsin drift-boundary, a post auger hole exposed two and one-half feet of soil and loesslike clay overlying yellow Kansan till with calcareous concretions.

At the quarter-corner on the east line of section 19, Little Rock township, a post hole showed the following section:

	FEET.
4. Soil, passing to leached loess below	1½
3. Loesslike clay; slightly sandy and with a few concretions in lower six inches	1
2. Sandy pebbly zone	½
1. Yellow-brown unleached Kansan till, with small calcareous concretions	

At the quarter-corner on the east of section 12, Grand Prairie township, a post hole showed the following:

	FEET.
3. Soil and leached loess	2½
2. Pebbly band	½
1. Yellow till	

Three miles south of Adrian at the southeast corner of West Side township a post hole showed the following:

	FEET.
3. Soil, becoming yellow at base	2
2. Unleached loess, slightly sandy	2
1. Yellow-brown Kansan till	½

The last three records are located along the crest of the ridge running south from Adrian which Professor Wilder interpreted as the Altamont moraine.[46]

Three miles west of Adrian at the southeast corner of section 16, West Side township, the road-cut showed two to three feet of soil and loesslike clay (leached loess). A few inches at the base of this zone is unleached in part of the exposure. Below this horizon is a coarse oxidized gravel which contains some masses of fresh Kansan till some of which are as large as two feet in diameter. The gravel zone is exposed to a depth of three to four feet and the basal part is cemented to a conglomerate.

The loess mantle in the Adrian region is thin, as the area is far to the northeast of the region of heavy loess, and so is similar to Clay and southern Dickinson counties farther south. The exposures east of Adrian are not of the typical leached loess, but sand grains exist more or less throughout the whole of it. It is, however, the equivalent of the loess mantle.

ORIGIN AND AGE OF THE LOESS.

That loess is of eolian origin has become firmly established.[46a] The chief source of the loess material of our region was the valley flats of the rivers forming the west line of the state, especially Missouri river, and because the prevailing winds of

[46]Iowa Geol. Surv., Vol. X, pp. 132-135, 1900.

[46a]A bibliography on loess is given in Iowa Geol. Survey, Vol. XXII, pp. 582-592. Professor Shimek discusses the matter briefly, from the standpoint of the evidence of western Iowa, in Vol. XX, pp. 399-405, and lists in a footnote on page 399 some of his more important papers on the subject.

the region are from the west, the thickness deposited and the extent of the mantle are greater to the east than to the west of the valleys. The greatest thickness was deposited near the Missouri and Big Sioux river valleys in western Woodbury and Plymouth counties, where the distinctive loess-formed topography now exists. With increasing distance to the east and northeast the thickness of the loess deposited was less and was only two to three feet over the eastern part of the Kansan drift-region of our area.

Little evidence exists in northwestern Iowa as to the exact age of the loess. It followed the accumulation of gravels in valleys of a region having a mature topography which was developed from the gumbotil plain of post-Kansan age. It preceded the Wisconsin epoch. The loess of eastern Iowa is closely associated with the Iowan drift-sheet and is commonly considered to be of Iowan age. The loess of western Iowa is believed to be of the same age.

The significance of the determination that there is loess over the entire extra-Wisconsin region is that it makes the drift of the entire region pre-loess in age, and since it was not possible to differentiate two drifts in the region, the whole extra-morainic portion of northwestern Iowa is classed as loess-covered Kansan.

CHAPTER IV

THE ASSOCIATED GRAVELS.

The Kansan till of northwestern Iowa has much gravel associated with it. Some of the gravel is in masses inclosed within the till, some is in masses at or near the surface, some in layers interbedded with the till and some is in bedded deposits in the valleys. The gravel in these several positions is very similar and seems to have had a common origin.

Gravel and Sand Masses Included in the Till.

GENERAL CHARACTERISTICS.

There is in the till of northwestern Iowa a large quantity of gravel and sand in the form of inclosed masses (gravel bowlders). These masses were observed in cuts, and in the fresher and steeper valley side exposures. When they are penetrated by bored or drilled wells, they are usually reported as gravel layers; but in dug wells their true nature is revealed in most cases. Most wells which stop in gravel masses which are supposed to be gravel layers give out in a short time.

The gravel masses differ in size from small pockets a few inches across to huge masses ten to twenty feet or more in diameter. Common dimensions are three to six feet. A mass exposed in a railway cut in section 6 of Douglas township, Ida county, about one and a half miles south of Washta, is thirty to forty feet by fifteen to twenty feet, and another in a Chicago and North Western railway cut just east of Sioux Rapids is twenty to twenty-five feet across.[47]

Most of the sand and gravel masses are roughly equidimensional or compressed in a vertical direction, but some are irregular in shape. Most of them have a rounded form, but several were seen with corners projecting into the till in such ways as could have been assumed only when the gravel masses were frozen.

The sand and gravel of the bowlders is as a rule stratified. The beds vary in position from approximately horizontal to vertical, and locally the layers are contorted. The bedding of a particular bowlder is as a rule a unit, but a few cases were observed which show faulting and some crushing, and in many cases the bedding is obliterated at the margin of the mass.

The material of these bowlders is sand, fine gravel, and some silts. Most of it is slightly ferruginous so that an iron-stained dust is released when the gravel is displaced. There are a few masses composed of old, badly rusted gravel. In general the coarse gravel is rusted and partly decomposed, while the finer material is fresh and unaltered. The coarse-grained igneous pebbles are more decomposed than the finer-grained ones, and the darker colored varieties (containing mica and hornblende)

[47]Professor Calvin described (Proc. Davenport Acad. Sci., Vol. 10, pp. 27-28, and figs. 9-13) a number of these masses inclosed in Kansan till, exposed in the railway cuts at Afton Junction and Thayer in Union county, and interpreted them as masses of Aftonian gravel which had been plowed up by the Kansan ice-sheet and inclosed in the till. One of these (p. 28 and fig. 12) is over a hundred feet long and rises more than twenty feet above the base of the cut.

more than the lighter colored. Most limestone pebbles are altered slightly at the surface and a few are altered to the center or decomposed to clay iron-stones.

Seventeen analyses of gravel associated with till were made, but there is some question concerning the correct interpretation of a number of these as gravel bowlders. The analyses of the nine positive cases average 39 per cent of igneous rocks and 61 per cent sedimentary rocks, 52 per cent being gray limestone. The average for the seventeen analyses is 41 per cent of igneous rocks and 59 per cent of sedimentary. Small rounded balls of till (clay-balls) were seen in a few of the gravel bowlders.

In most cases the till is fresh up to the edge of the gravel bowlder, but in a few cases a thin shell, concentric with the border, is stained, altered, and partly cemented with ferruginous material. Also in a few cases the gravel is cemented in a shell around the outside of the mass. This alteration and cementation is a contact phenomenon which has been produced since the inclusion of the gravel mass.

DESCRIPTION OF SOME TYPICAL GRAVEL MASSES.

Little Sioux river valley across northern Buena Vista and southern Clay counties has been cut deeply into the till and both natural and artificial exposures along the valley show many gravel bowlders. A large sand bowlder in a cut of the Chicago and North Western railway just east of Sioux Rapids has been noted above (page 358), and gravel masses are numerous in several cuts a little farther east. In the southeast quarter of section 3, Barnes township, Buena Vista county, just east of where the railway crosses the terrace area is a cut, which, although old and slumped, showed a great number of sand bowlders.

Near the top of the bluff north of the schoolhouse at Peterson, there is a pit excavation thirty to forty feet across and fifteen to twenty feet deep. The material excavated was supplied by several large sand and gravel bowlders packed closely together. Some of the vertical contacts with the inclosing till were exposed. Some of the material is coarse gravel, some is fine sand, and some is silt. The material is stratified, and the beds now stand at various angles. Near the top of the slope leading to the upland southwest of Peterson the road-cut exposed a lens of sand fifty feet long and ten feet thick. The material is slightly iron-stained and around the edges of the mass is somewhat contorted.

A large sand bowlder is exposed in a road-cut on the slope toward the river in the north half of section 26, Waterman township, O'Brien county, and at about the center of section 14 of the same township, the east bluff of Waterman creek shows several gravel bowlders, four to ten feet across, inclosed in Kansan till.

In the north bluff of Storm lake, near the center of section 4, Hayes township, Buena Vista county, there are several irregular masses of loesslike silt and sand. At several places the layers making up the masses are contorted and crumpled and even broken off, so that they abut against other parts of the mass in which the layers have a different angle.

Just east of the center of section 22, Brooke township, Buena Vista county, the west bank of a ravine exposes an old-looking, ferruginous sand and gravel with some fine silty layers. The exposure has a length of about fifty feet and rises forty feet above the ravine bed to the top of the slope. In either direction the ravine slope is grassed over and the basal part of the exposure is too badly slumped to show material in place, but Kansan till was exposed in the ravine bed just south of the exposure and rose six to eight feet above the ravine bed just north of the exposure. There is little doubt that this is a great gravel mass included in the Kansan till. The bedding of the mass dips slightly to the south and apparently back into the bank to the west. Ferruginous concretionary cementation has affected part of the sand and has formed irregular shaped masses some of which are more than a foot across. The material composing this mass is much more decomposed and altered than is common for the gravel masses.

In the north part of Cherokee, in an alley just east of Second street and south of Spruce street, there is a large mass of silt and sand, partly inclosed in till. The material is somewhat contorted and the layers are in part steeply inclined. A series of road-cuts in Kansan till in the northeast quarter of section 28, Cherokee township, showed in 1916 a large number of inclosed gravel masses. The face of one of these cuts near the north line of the section showed almost as much gravel as till.

Other gravel masses were seen in the south bluff of Mill creek, between the bridges in the northeast quarter of section 23, Cherokee township; in the bluffs of the creek valley of section 24, Cedar township; along the creek valley through sections 11 and 10, Pilot township, south of Cherokee; and at many other places throughout the area. In fact most large exposures of till show some of these gravel masses.

In the south bank of a ravine in the south part of section 10, Stockholm township, Crawford county, about a quarter of a mile west of the railway there are several gravel bowlders four to ten feet in diameter and some smaller ones of sandy silt or silt. The material of these gravel bowlders is somewhat iron-stained and in one case the gravel around the border is partly cemented, while in another the surrounding clay is iron-stained for two to three inches, concentric with the border of the bowlder. The analysis of pebbles from one or these bowlders gave 30 per cent igneous rocks and 70 per cent sedimentary rocks, 7 per cent of which were clay-balls. The layers of the gravel composing the bowlders are inclined.

In the south bank of the road-cut just east of the railway crossing in the east part of section 15, east of Sioux Falls, South Dakota, there is a mass of gravel completely inclosed in the Kansan. The gravel is rather fresh and contains shale pebbles and drift pebbles. The analyses showed 49 per cent igneous rocks and 51 per cent sedimentary. The bedding of the mass is inclined.

THE ORIGIN OF THE SAND AND GRAVEL BOWLDERS.

The presence of the rounded, rectangular or angular masses of stratified gravel, sand and silt completely inclosed in the till has been noted. It has also been noted that some of these gravel masses have angular corners projecting into the till, and that the layers of the masses have various positions. These points indicate that the gravel masses are fragments of larger deposits which were broken up, probably while they were in a frozen condition, and the fragments were incorporated like rock bowlders in the till. However, what was the origin of the gravel deposit that was thus broken up and what was its age? Two hypotheses are considered. (1) It was an interglacial deposit which existed in the region prior to the Kansan ice-epoch; (2) It was an outwash deposit laid down in front of the advancing Kansan ice-sheet which a little later plowed it up.

An interglacial deposit should consist largely of pebbles of the harder, more resistant types of rock that are left after the weaker ones have been worn out or decomposed, and in this respect the gravel of these masses does not seem to be interglacial. The gravel masses exposed in the railway cuts at Thayer and Afton Junction were interpreted as masses of Aftonian gravels, which are very abundant in that region. However, in northwestern Iowa, as will be shown later, the Aftonian gravels are practically absent.

In general appearance and freshness the pebbles of the gravel masses bear a close resemblance to pebbles picked directly from the Kansan till. The clay-ball pebbles also have a definite bearing on the age of the deposit. Since these clay-balls are of Kansan till, the gravel deposit in which they exist cannot be older than Kansan, and is therefore not Aftonian. Since the gravel masses are inclosed in the Kansan till these masses cannot be younger than the Kansan.

The gravel masses are therefore considered contemporaneous with the Kansan till-sheet which incloses them and the gravel is interpreted as having been deposited beyond the front of the advancing ice-sheet which a little later plowed it up and incorporated fragments of the frozen mass in its drift.

The Gravel Hills.

At a number of places within the area of the Kansan drift there are mounds composed of gravel and sand. Their slopes are gentle and few of them are more than fifteen to twenty feet above their surroundings. In form, they resemble the kames of the Wisconsin drift, though they are much less conspicuous. Some of them are isolated, and some are in groups.

NATURE OF THE GRAVEL.

The gravel of these hills is as a rule fresh, or but slightly altered. Some of the exposures, however, show iron-stained and decomposed gravel, and a few show an abundance of chalky, calcareous material either as weathered limestone pebbles or as matrix between the pebbles. Extreme alteration was seen near the surface at a few places, giving an iron-stained clayey mass of pebbles.

As in all types of gravels of our region, gray limestone pebbles predominate to such an extent as to make a light colored gravel. In twenty-three analyses made in gravels of this type the limestone pebbles average 56 per cent of the whole. Shale pebbles are present and in certain layers are even abundant. Grains of shale also are abundant in the sand. A characteristic and distinctive feature of these gravel hills is the presence of small rounded masses of glacial clay (clay-balls) among the pebbles. These differ in size from a fraction of an inch to six inches in diameter. They are recorded in seventeen of the twenty-three analyses of gravel from these hills and some of the analyses not recording them were made before the clay-balls were noted. The average for the twenty-three analyses is 11 per cent. The percentage is twenty-six or below in all analyses but one, where it is 59. The igneous rock content ranges from 17 per cent to 35 per cent, except in one analysis where it drops to 8 per cent because of the large number of clay-balls. Counting the clay-balls as sedimentary, the average total of sedimentary rocks is 75 per cent, and the average total of igneous rocks is 25 per cent.

The percentage of granite and other igneous pebbles generally is low in comparison with that shown in analyses from gravel deposits of other types. This is due to the large number of clay-balls in these gravels, which by their presence lower the percentage of all other kinds of pebbles. The decrease, however, comes mainly in the igneous pebbles, for the comparison is with gravels that have been more waterworn, and which therefore contain a smaller percentage of pebbles of the softer materials. Chief among these softer pebbles are the clay-balls which would be destroyed by wear, and thus would increase the percentage of all other kinds. But some pebbles of other soft materials would be destroyed by the transportation, so that the increase would be most apparent in the harder types. The increase in the percentage of limestone pebbles due to the destruction of clay-balls apparently was offset by the destruction of some of the softer limestone pebbles, with no apparent gain in limestone.

If these gravel hills are kames or some other type of deposit directly associated with the ice, softer material would naturally be more abundant than in gravels that were subjected to longer transportation and wear. On the other hand, waters flowing well up in an ice-sheet, as may be the case with waters forming kames, probably would yield a larger percentage of igneous pebbles than waters draining from the base of the ice.

There is in some cases a great range in the composition of the gravel in the same hill. This is particularly prominent in the case of shale pebbles, for certain layers contain a percentage far above normal, and some layers are made up almost entirely of small grains of shale. In other constituents also there is in some cases a considerable range. No differences were detected that differentiate the deposits of different localities. Analyses from gravel hills a hundred miles apart are as likely to be similar as those from hills near together.

DISTRIBUTION AND DESCRIPTION OF THE GRAVEL HILLS.

Northeastern Lyon County.—A number of gravel hills in the northeast corner of Lyon county, north, northwest and west of Little Rock, form the most conspicuous instances of these hills in the Kansan area. Most of them are below the general upland level and are on the slopes of Little Rock river valley. Most of them rise only ten to fifteen feet above their surroundings, but one in the southeast quarter of section 23 rises twenty-five feet above its surroundings, enough to make it a rather prominent feature, especially from the valley to the south. It is figured in the Lyon county report[48] and there interpreted as part

[48]Iowa Geol. Surv., Vol. X, p. 133, 1900.

of the Altamont moraine. A group of hills just north of Little Rock, near the center of section 26, contains several gravel pits in relatively fresh material, while the highest hill in the southeast quarter of section 23 shows beneath the surface several feet of ferruginous, decomposed coarse gravel.

In the southwest quarter of section 27 there are a number of gravel hills. A pit in the one at the southwest corner of the section shows a coarse somewhat rusted gravel in which the coarse-grained igneous pebbles crumble readily. The gravel of this exposure, as well as that of section 26, contains many clay-balls. Other low gravelly hills, without exposures, are found in the west half of section 34 and the east half of section 33.

Southwestern Nobles County, Minnesota.—A large number of gravel hills are found in the southwest part of Adrian, Minnesota, and in the northeast quarter of section 23, half a mile farther southwest. A road-cut in one of these hills on the north line of the northeast quarter of section 23 showed a great mixture, including coarse dirty gravel with clay-balls; ferruginous bowldery deposits in which many of the dark igneous bowlders are rotten; fine fresh sand; great masses of till; and mixtures of gravel, bowlders and till. The areas northwest of Little Rock and southwest of Adrian were interpreted by Professor Wilder as parts of the Altamont moraine of Wisconsin age.[48a]

Three miles south of Adrian, in the southwest quarter of section 36, West Side township, a pit in a low hill on the north slope of a shallow valley shows in part coarse pebble beds, and in part fine gravel and sand. Clay-balls are abundant in the coarser part, an analysis giving 16 per cent. The coarse-grained dark igneous pebbles crumble easily and most of the limestones are coated brown. In a part of this hill the layers are steeply inclined and in these layers the laminæ lie at an angle of 80 degrees.

Western Osceola County.—In the west part of Osceola county there are low gravel hills on the north slope of a broad, shallow valley in the west part of section 5, West Holman township, and six miles south in the southwest quarter of section 5, and the southeast quarter of section 6 of Gilman township. In the hill in southwest 5, Gilman township, a pit exposure showed about three feet of coarse ferruginous gravel resting upon fresher finer-grained material. Clay-balls are very abundant, amounting to 25 per cent of the total contents in one analysis, and on the pit face one was exposed for each square inch of surface.

Northern O'Brien County.—Gravel hills are found along the headwaters of Floyd river in northern Franklin township of O'Brien county. On both slopes of a tributary valley in the southwest quarter of section 4, there are several hills with gravel exposures and hills which have the same topographic form appear on the north of the main valley in the southeast quarter of section 4. The exposures seen were shallow and the gravel was greatly decomposed. A low hill just northwest of Sheldon in the central part of section 25, Grant township, Sioux county, is probably a gravel hill.

In a pit in a low mound three miles northwest of Hartley, near the center of section 24, Lincoln township, the gravel had been worked out in several places and there was exposed a vertical contact between the gravel mass and the till. This gravel mass, partly inclosed within the till, occupies an intermediate position between the gravel hills and the included masses of gravel.

[48a] Iowa Geol. Surv., Vol. X, pp. 132-135, 1900.

Farther east, in Waterford township of northeastern Clay county, there are several low hills or mounds apparently composed of gravelly material.

Along Willow Creek in Southern O'Brien County.—One of the regions of greatest abundance of the gravel hills is along Willow creek west of Calumet in southern O'Brien county, where more than a dozen of these hills are present in the north parts of sections 22, 21 and 20 and the south parts of sections 16 and 17, Liberty township (Plate XV). About half of these have exposures showing sand and gravel. The two best exposures are in gravel pits in the north part of section 22 and will be described somewhat in detail.

Near the quarter-section corner on the north of section 22 there is a low mound near the top of the valley slope with a pit twenty to twenty-five yards across and ten to fifteen feet deep. The material exposed is sand and fine gravel, with some very fine-grained horizons showing extremely fine lamination. Throughout the lower part of the mass the horizons are inclined, with a strike N. 25°-30° W. and a dip of 45°-50° in a direction south of west. The individual horizons are cross-bedded and laminated. Where the tilting of the mass increased the inclination of the cross-bedding laminae, these now stand at an angle of 60°-70°. Where the laminae were originally inclined in the direction opposite to the direction of tilting of the mass, the original inclination was overcome and the laminae are now inclined 20° to 30° in the opposite direction (figure 48).

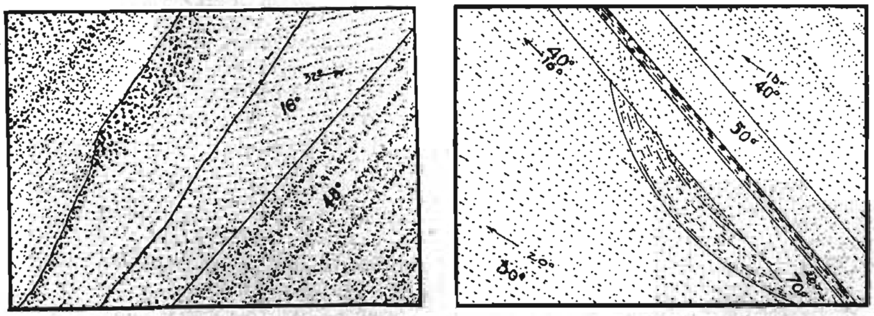


FIG. 48. Sketches showing cross-bedding and basin structure of sand exposed in a pit in a gravel hill in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county. The present inclination of the beds is given in the more prominent figures. The direction of inclination before the tilting of the gravel mass is indicated by the arrows, and the angle by the less prominent figures. The position of the beds at the time of deposition may be shown by tilting the figure on the left, to the right about 50 degrees, and the figure on the right, to the left the same amount.

Gray limestone pebbles are by far the most abundant, forming 66 per cent in one analysis. A few shale pebbles appear in all the material, but are most abundant in the finer gravel layers where they form a third to a half of the whole number, and decrease in abundance with the increase in size of the pebbles. Interbedded with these layers containing much shale are other layers of nearly the same coarseness that have only a few shale pebbles.

The following section records the material shown in this pit which dips to the southwest (figure 49).

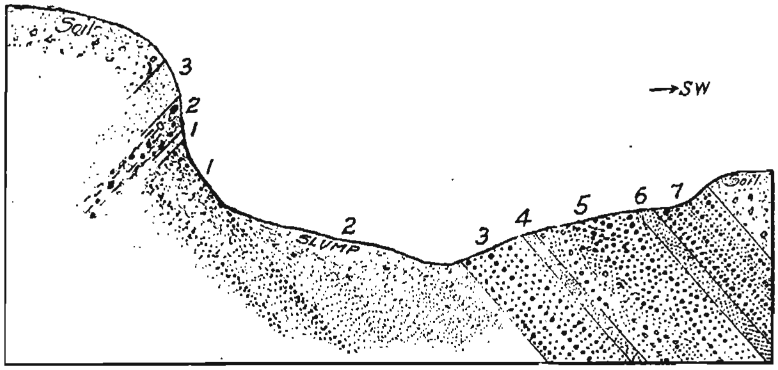


FIG. 49. Cross section of pit in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county, showing the structure and the relation of the parts described in the text. The numbers on the figure are the numbers of the zones of the sections recorded below.

		FEET.
7.	Fine reddish gravel, exposed	4
6.	Very fine-grained yellowish gray sand, cross-bedded and finely laminated	1
5.	Coarse sand and fine gravel, laminated and cross-bedded in part; coarse gravel and pebbles at base	7½
4.	Fine cross-bedded sand	1
3.	Sand and fine gravel; some layers contain much shale	4½
2.	Slumped slope of fine sand	11
1.	Coarse sand, giving place to fine clayey sand, exposed	2

Resting across the edges of the lower horizons of the section just noted, and exposed in the east face of the pit are the following:

		INCHES.
3.	Sand	12-18
2.	Glacial till	12-18
1.	Sand	6

These three members have a strike similar to that of the horizons below, but dip in the opposite direction (northeast) at an angle of about 50° (figure 49). The till horizon thins to left and right, forming in the pit face a lens-shaped exposure about fifteen feet long. It may be either a mass of till put down upon the large gravel mass or the thinning edge of the surrounding till which appears partly to inclose the gravel mass. If the gravel were entirely worked out the contacts might throw much light on the relation of the gravel masses and the till. Above these three members in the pit face is a jumbled mass of pebbles, bowlders and clay material three to four feet thick and then a sandy, pebbly soil horizon of two feet.

Just south of the northwest corner of section 22 is a large pit in a gravel hill on the south slope of the valley. This is the largest of these hills along this creek and rises forty feet above the stream, although its top is only slightly higher than the upland just to the south. The material here is somewhat coarser than in the last pit described. Clay-balls are quite abundant in some zones and averaged 20 per cent in three analyses. They range in size from small pebbles to masses six to eight inches across. The material is stratified and the horizons are inclined with a strike N. 40°-50° W., and a dip of about 20° SW. The following section is exposed in this pit.

		Feet.
10.	Gravelly soil	1½
9.	Alternating layers of sand and gravel	3
8.	Coarse reddish gravel	2½
7.	Fine cross-bedded sand	3
6.	Coarse gravel or pebble horizon. Contains numerous clay-balls ranging in diameter from 1 to 8 inches. This horizon is variable. At the east end of the pit it contains a 4 foot layer of fine cross bedded sand, which thins out entirely in 40 feet to the west. At the central part of the pit face it is very bowldery. At the west end it is fine gravel with a few pebble layers	15±
5.	Poorly exposed coarse sand and fine gravel. Some of the gravel layers are moderately rusted	15
4.	Fine sand with delicate lamination and cross-bedding. Horizontally this grades into coarse sand not distinguishable from No. 3	1½
3.	Cross-bedded grayish sand with a large percentage of grains of shale. Some layers are so largely of shale that they are sticky like clay when moist	2½
2.	Coarse reddish cross-bedded sand containing clay-balls in upper part. Only partly exposed	8
1.	Poorly exposed fine yellow-gray sand	10

In the north part of section 21, and the south parts of sections 16 and 17, farther down Willow creek valley, there are more of these hills, several of which show shallow exposures of gravel. In the southeast quarter of section 17 a small abandoned pit in one of these hills (figure 50) showed gravel containing 59 per cent of clay-balls.

Northern Cherokee County.—Near the south line of section 10, Cedar township, Cherokee county, a mile north of Larabee, there is a gravel hill that has been worked for a number of years. It is located on a divide and stands ten to fifteen feet above its surroundings. Another hill about half a mile to the north is of similar size. The pit exposure in the first hill shows relatively fresh coarse gravel in inclined layers. Clay-balls are plentiful and some are as much as six inches in diameter, and the pit face showed a lens of till five feet long and four to eight inches thick. This hill was mentioned by Professor Macbride in his report on Cherokee and Buena Vista counties, and was interpreted as being "part of a continuous series of such deposits extending from Sibley south and east, including the gravel pit at Sheldon and similar deposits about Calumet."[49] The deposits at Sibley and Sheldon are valley deposits, while the "deposits about Calumet" probably refers to the gravel hills along the headwaters of Willow creek described above. The suggested "continuous series of deposits extending from Sibley south and east" does not exist, although there are several points to suggest such a series.

One mile south of Larabee, on the east side of the railway, at the center of the northwest quarter of section 26, an abandoned pit in one of these hills shows a rather rusty gravel with many clay-balls. In the north half of the southwest quarter of section 34 are several hills, one of which has an exposure showing the usual light-colored gravel with clay-balls.

Southeastern Cherokee County.—In southeastern Cherokee county there are gravel hills at many places in Pitcher and Diamond townships. They are most numerous along a ridge which extends from the northwest quarter of section

[49] Iowa Geol. Surv., Vol. XII, p. 322. 1902.

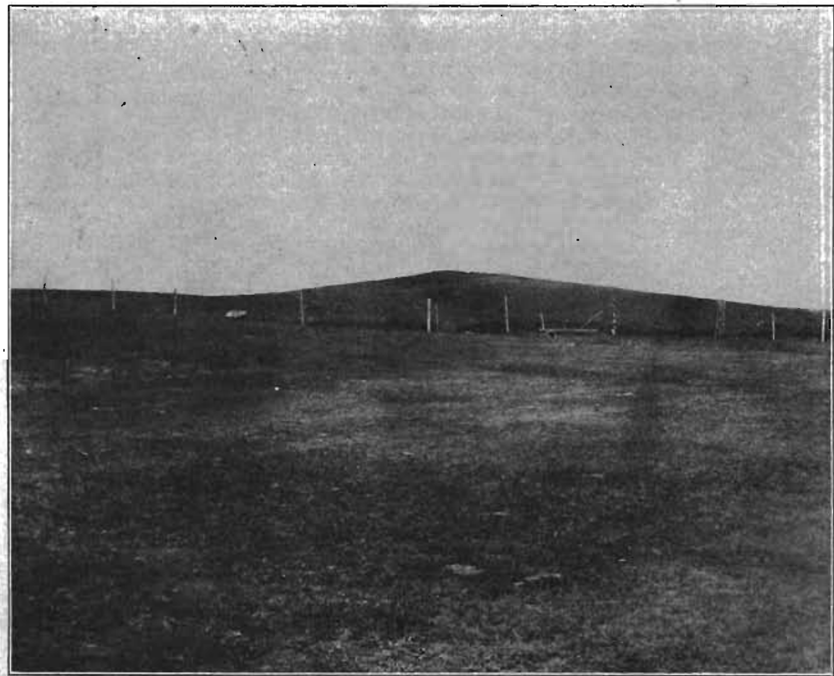


FIG. 50. Gravel hill on the north slope of Willow creek valley in the southeast quarter of section 17, Liberty township, O'Brien county.

28, Pitcher township, southeast across this section and south through the east part of section 33. Pebbly mounds appear on this ridge just northwest of the center of section 28, in the southwest quarter of section 28, at the northeast corner of section 33, and at a number of places in the east part of section 33. A group of hills near the quarter-corner on the east line of section 33 have been worked for sand for many years. There are other pebbly hills near the center of section 21, and in the northwest quarters of sections 22 and 9. The pebbles, as exposed at the surface of the mounds, show only the hardest varieties of rock, but in the pits and road-cuts on the east line of section 33 all the usual kinds of pebbles are present, with some clay-balls. The material in general is more ferruginous than is common farther north, but in the pits just noted there is much fresh fine-grained sand. Gravel hills containing very ferruginous sand appear also in the east part of section 4, Diamond township.

In the northeast quarter of section 35, Diamond township, there is a group of gravel hills which extend also into the adjoining corners of sections 26 and 25 (Plate XV). The shallow exposures in this group of hills show greatly altered material with rotted igneous pebbles and limestone pebbles altered to clay ironstones, but some deeper exposures in gravel pits show fresh gravel and sand. In the northeast part of section 25 there is an isolated, steep-sided, kamelike hill on the south slope of Little Maple river valley.

The great alteration of the gravel of many of the gravel hills of Diamond township raises the question whether they are of the same age as the hills farther north. Their position would make them the same but the material in the upper part of some of them looks older. However, alteration is not merely a matter of age. The more frequent the alternation of the presence of water and air in the gravel, the more rapid the alteration. Neither water nor air remaining permanently in a deposit will produce much change. The hills of section 35 are in a region of considerable relief where there would be fairly rapid motion of the ground-water and notable fluctuation of the ground-water table with each successive period of rain. Under these conditions alteration would be more rapid than in the more level regions farther north.

Northeastern Ida County.—In northeastern Ida county, on the northeast quarter of section 15 and the southeast quarter of section 10, Galva township, there is a group of low mounds with pebbly surfaces, of which one on the section line has an exposure showing a ferruginous dirty gravel with clay-balls. Other low mounds with pebbly surfaces are located in the northeast quarter of section 24, where a dozen or more low swells show pebbles; in the northwest quarter of section 12; the north half of section 23; the northwest quarter of section 25; and in Silver Creek township to the south, in sections 9 and 8, on the slope of Silver creek valley.

Sac County.—Just southeast of Early in the northcentral part of Sac county, only one to three miles from the Wisconsin drift-boundary, gravel hills with pit exposures are found in the southwest and northeast quarters of section 10. Boyer Valley township. The surface of the hill at Early on which the water tank is located is pebbly and five miles south of Early a low gravel hill is located just east of the southwest corner of section 34. The material seen in the pits at the southwest corner of section 10 consists of iron-stained gravel and fresher cross-bedded sand. The coarse-grained igneous pebbles and bowlders are much decomposed, and even some of the limestone pebbles are altered. In his report on Sac and Ida counties, Professor Macbride mentions gravel deposits in and about Early;[50] gives pit sections from both the gravel hills of section 10; and shows gravel pits on the Sac county map in section 10 southeast of Early and in section 31 west of Lake View. Concerning these gravel deposits he says they "represent probably an overwash from the drainage of the Wisconsin front." All these hills are well up toward the top of the divide between Boyer river and Indian creek, a mile to two miles west of the Wisconsin drift-margin, which lies along Indian creek valley (page 258). Kansan drift topography intervenes between this drift margin and the gravel hills, and there is no evidence that the Wisconsin ice occupied any part of the area west of Indian creek, or drained across this divide. The topographic position of the hills and their isolation from the Wisconsin drift-margin show that the material was not derived from the Wisconsin ice margin.

One mile north of Wall Lake, in the central part of section 1, Levey township, there is a group of gravel hills, covering fifteen to twenty acres, which have been extensively worked for a number of years for road ballast. The material here is light-colored gravel with a high percentage of limestone pebbles and is much fresher than most of the material of the gravel hills south of Cherokee. In one of the pits there is much light yellow siltlike material

[50]Iowa Geol. Surv., Vol. XVI, p. 540, 1906.

mixed with the gravel. Gravel hills are frequent also along the west line of section 1, Levey township, and in Clinton township, in the northeast quarter of section 32, the northwest quarter of section 35 and the southwest and northeast quarters of section 26.

South of Wall lake outlet, in the north part of the southwest quarter of section 19, Levey township, a pit on a valley slope exposes a fine gravel with much limestone. Clay-balls are abundant and the material is evidently of the gravel hill type. Gravelly swells are found also near the quarter corner on the south of this section. In the northeast quarter of the southwest quarter of section 20 there is a gravel pit in a shoulder on the east slope of the valley that forms the Wisconsin drift-boundary. The material is a dirty gravel containing many clay-balls and masses of till. This appears to be one of the gravel hills of the Kansan drift-region although the surface just to the east shows Wisconsin drift topography.

ORIGIN OF THE GRAVEL HILLS.

Evidence of Structure.—Most of the gravel is stratified, and many of the individual layers are themselves beautifully cross-bedded and finely laminated. Most of the deposits that are adequately exposed show the layers inclined at a considerable angle. In the pits just northwest of Calumet the gravel layers have an inclination of 58°, while some of the cross-laminae are inclined as much as 70° (figure 48). Other masses showing tilted layers are found in section 10, one mile north of Larabee, and in the southwest quarter of section 36, three miles south of Adrian, Minnesota, where cross-laminæ have an angle of 80° (page 364). These angles are well above the highest possible angle of deposition, and the strata have come into their present position by a tilting of the mass since the deposition of the gravel. The strike and dip of the beds in most cases are uniform in a particular gravel hill, indicating that the tilting affected the gravel mass as a unit.

Evidence of Location.—Most of the gravel hills are located along valleys or on the slopes of valleys. The most notable instance of their location along valleys is along Willow creek, west of Calumet, in southern O'Brien county, but other examples were noted in northern Franklin township of O'Brien county; five miles west of Sibley; and three miles south of Adrian, Minnesota. The pronounced development of these hills north and northwest of Little Rock (page 363) is within or on the slopes of Little Rock river valley. From the valleys, these hills may appear prominent but their tops are seldom higher than the upland, and from the upland they are hardly recognizable. Some of the hills are located on divides.

Evidence of Material.—One of the characteristics of these gravels is the presence of the clay-balls seen in most of the exposures. Balls of clay, even when frozen, cannot be supposed to have withstood the wear of transportation by running water for a very long time, and these clay-balls, therefore, indicate that the material was not carried great distances before deposition. The large percentage of shale and other soft materials found in some of the exposures and the prevalent subangular form of the pebbles, point to the same conclusion.

The clay composing the clay-balls is typical Kansan till, and therefore the gravel containing them cannot be older than the Kansan ice-sheet. But the gravel containing the clay-balls is at many places partly inclosed in Kansan till, and there seems to be no division between these masses and those completely inclosed in the till, and which likewise contain clay-balls. The deposit cannot, therefore, be younger than the Kansan ice-sheet.

In general appearance these gravels look very much like the gravel masses included in the till, like the gravel interbedded with the till, and like the valley gravels. The pebbles of the gravel are very much like those of the Kansan till, and from its general appearance the gravel might have been derived from this till.

Conclusions.—As has been noted these gravel hills have the form of kames and one hypothesis as to their origin is that they are kames formed during the retreat of the Kansan ice-sheet. However, the surfaces upon which these hills stand are not constructional but erosion formed, and as is shown elsewhere (page 332) there is reason to believe that the entire surface is below the original Kansan drift-plain. Also the uniformity of strike and dip throughout one of the hills, the distinctly bedded character of the material, and the well developed lamination and cross-bedding show a regularity too great for kame deposits.

The evidence of structure and material noted above links these gravel hill with the inclosed gravel masses. They differ from the gravel masses only in being at the surface instead of beneath the surface. They are interpreted as gravel masses which were formerly inclosed in the Kansan till, but by the erosion of the overlying till they have been brought to the surface. They are within and on the slopes of valleys where erosion is most rapid. They stand as mounds upon the slopes because the gravel is more resistant to erosion than the till, and they have slowly become elevations by the removal of the inclosing till just as a resistant rock material comes to stand above its surroundings by the greater erosion of the surrounding area. Gravel erodes more slowly than till because it is more porous and there is greater percolation into the gravel and less surface drainage.

The gravel masses originated in the same way as explained for the inclosed gravel masses (page 361). That is they are fragments of a deposit formed in front of the advancing ice-sheet which a little later plowed up the deposit and incorporated frozen masses of gravel in its drift. These masses were tilted into various positions so that the originally horizontal bedding is now inclined at various angles.

Interbedded Gravel and Till.

Exposures showing till interbedded with sand and gravel were seen at a number of places within the Kansan area, especially in northern Cherokee county. The sand and gravel are mostly fresh and the latter is mostly fine. Coarse sand with pebbles scattered through it is common. Some of it is distinctly bedded and some shows no stratification. Locally the gravel is cemented by a calcareous cement and so forms irregular masses of firm conglomerate; or cementation may affect the whole or part of a stratum over a considerable area. Cementation is more common at the top of the gravel zones than at the base, and apparently is more common on the face of an exposure than farther back from it.

DISTRIBUTION AND DESCRIPTION OF EXPOSURES.

By far the greatest example of the interbedding of gravel and till observed, is that found in the east bluff of Mill creek in the west half of section 14, Cherokee township, three miles north of Cherokee. Mill creek, at this place, flows against the base of the east slope of its valley, and this slope rises very steeply 100 to 120 feet to the crest of a narrow ridge which overlooks the valley of Mill creek on the west and the Little Sioux valley on the east. The good exposures are just south and north of the line through the center of section 14, distributed through a distance of about eighty rods, and are found in little gullies and slides that give exposures of the underlying material. The lower thirty to forty feet of the valley slope is gentle but shows a few exposures of the typical Kansan till. Above this is a steep slope of seventy-five to a hundred feet, consisting of about equal parts of interbedded till and gravel which alternate several times in the vertical section. The gravel horizons vary in thickness from mere seams to twenty feet, but a common thickness is ten to fifteen feet.

Most of the gravel is fresh and has a light color due to the predominance of gray limestone pebbles. It contains many clay-ball pebbles from the associated Kansan till, and some of Nebraskan till. The interbedding of gravel and till and the presence of the clay-balls of the associated till in the gravel, show that the gravel belongs to the same stage as the till. The general appearance and composition of the pebbles also indicate that they were derived from this till.

These exposures in the Mill creek bluff of section 14 are such good ones that the following sections are given, recording in detail the succession found in several of the better exposures. The exposures are all mere gully washes and are partly obscured by slumping and surface accumulation. The sections are given in order from south to north.

Section A.—If approach is made from the south, the first exposure that is seen that covers approximately all of the height of the slope, is thirty to forty rods south of the quarter-section line. This exposure is shown diagrammatically in A of figure 51.

		FEET.
11.	Grass-covered gravelly clay slope rising to the top of the ridge, which is here 106 feet above the creek. Probably till, but it may contain some gravel layers	12
10.	Light brownish gray till with pebbles and cobbles.... The exposure is not entirely continuous and the division may contain some gravel. Numbers 11 and 10 combined would make a till zone 30 feet thick, which is greater than for any single zone of till known along this bluff. There is also the unexposed zone (9) below, which may be largely till. It is not probable that numbers 11, 10 and 9 form a single continuous till zone or even that numbers 10 and 11 are without a single gravel layer.	18
9.	Unexposed slope	10

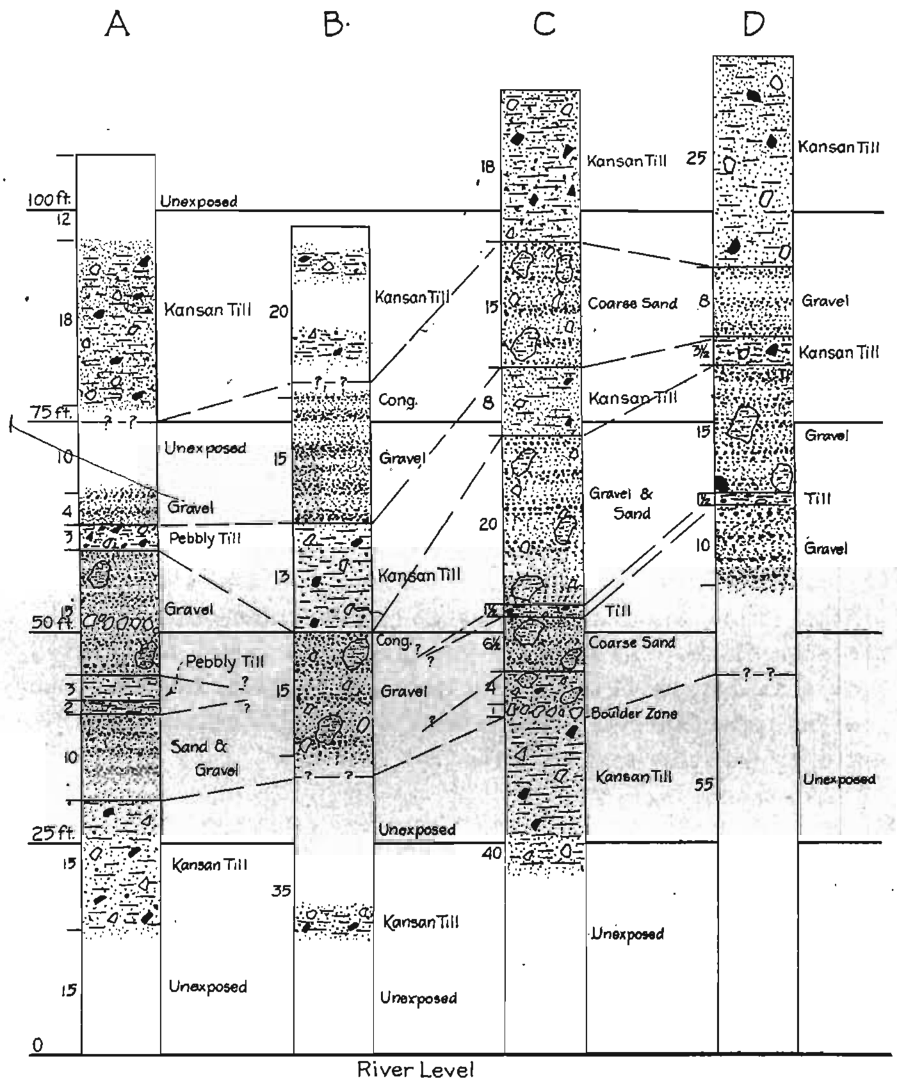


FIG. 51. Columnar sections of exposures in the east bluff of Mill creek in the west half of section 14, Cherokee township. The probable correlation of the numbers of the several sections is indicated.

8. Light-colored gravel................................ 4
7. Light brownish gray till with pebbles, cobbles and small ocherous masses. In some places the pebbles and cobbles make up fully half of the whole. The basal contact on the gravel is very sharp, without any alteration or deformation of the gravel....... 3
6. Gravel with large pebbles and bowlders scattered through it and a layer of bowlders about 5 feet above the base. Many included clay-balls and

masses of till are present. The gravel has a light color and limestone is the dominant material. Shale pebbles are quite abundant. This is the typical gravel associated with the fresh till.......... 15

5. Brownish yellow till which breaks into elongate chunks 3
4. Brownish blue-gray sandy till. In the line of section it is 8 inches thick, but it thickens abruptly to the north, being 2 feet thick only 3 feet away. This may be a lens of till........................ ⅔—2
3. Sand and gravel; at top a fine yellow sand; only partly exposed 10
2. Slope with several exposures of oxidized brownish yellow Kansan till 15
1. Unexposed slope to creek level..................... 15

This section gives at least three gravel zones and four till zones, and a better exposed section probably would increase the number.

Section B.—The gully just north of the quarter section line fence exposes the following, beginning ninety-eight feet above the creek and passing downward. The columnar section is shown in B of figure 51.

FEET.

5. A pebbly clay slope with a few exposures of brownish gray till 20
4. Gravel horizon; cemented to a conglomerate near the top 15
3. Brownish yellow-gray till; harder and more compact than number 5. Where it is fresh it breaks into irregular chunks and crumbles to a sandy clay. The lower 3 feet includes much gravel............... 13
2. Light-colored gravel with pebbles, cobbles, clay-balls, and some larger masses of till 15
   In the gully the upper 2 feet of this horizon is cemented, forming a calcareous conglomerate, but this does not continue horizontally beyond the gully. The lower part of the slope is so badly slumped that the lower contact of the gravel could not be exposed
1. Unexposed to creek level, except for one small outcrop of oxidized, brown Kansan till at 15 feet above the creek 35

This section shows two distinct layers of fresh gravel, each at least fifteen feet thick, and each overlain by Kansan till. A cemented zone is found at the top of each gravel layer. The cementing material is calcareous and the cementation is sufficient to make firm conglomerate, large blocks of which lie on the slope below the outcrop. The cemented parts differ in thickness and seem to be irregular, cemented masses rather than continuous beds. This cementation is due to the evaporation which takes place when ground water percolating downward passes from the compact till to the porous gravel. If the water has become saturated with calcareous material, this evaporation will cause deposition. The air within the gravel horizon is frequently in motion in order to equalize air pressure within the gravel mass with the changing atmospheric pressure outside, and this favors evaporation by preventing the air from becoming saturated with moisture. The greatest motion of the air within the gravel zone would be at the top, and near the face of the exposure, and in these places the greatest cementation is found.

Section C.—This exposure is in a gully about forty rods north of the quarter-section line fence. It is shown in C of figure 51.

		FEET.
9.	Gravelly clay slope	18
8.	Ferruginous coarse sand with pebbles, cobbles and clay-masses	15
7.	Sandy brownish gray till which breaks out in irregular chunks and pulverizes to a sandy clay	8
6.	Ferruginous gravel or coarse sand with pebbles, cobbles and numerous large clay-masses, some of which are 2 to 4 feet across	20
5.	Bluish gray till with brown streaking along joints	1½
4.	Coarse sand with pebbles, a few cobbles and clay-balls. The lower 18 inches is about half clay in the form of clay-balls	6½
3.	Yellowish brown till with many pebbles and pockets and seams of sand	4
2.	Coarse gravel with cobbles and bowlders	1±
1.	Brown Kansan till was exposed for 18 inches below the top of the layer and at one point 10 feet lower. Remainder of division to creek level unexposed	40

Section D.—At the place where the bluff begins to bend to the west there is a gully which branches about fifty feet above the creek. The following exposure was seen in the north branch of this gully. It is represented in D of figure 51.

		FEET.
7.	Pebbly clay slope rising to the crest at 118 feet above the creek	25
6.	Gravel with clay-balls	8
5.	Brownish gray till	3½
4.	Gravel with cobbles and clay-masses	15
3.	Brownish yellow plastic sandy till	1½
2.	Gravel with clay-masses	10
1.	Unexposed to water level	55

Several other exposures to the north show a part of the section and in every case where more than a few feet is exposed an alternation of gravel and till is to be seen.

The beds of all these gullies are filled with bowlders. Pink and gray granite of the fine-grained type predominate, but basalts are numerous and limestones are more prominent than is common among bowlders.

The sections given above show two, three and four gravel horizons, and few of the exposures were continuous enough to demonstrate that other thin gravel layers are not present. Some similarities of sections which are very close together were noted, but on the whole it appears that the individual horizons are not continuous throughout the length of the bluff. Figure 51 shows such correlations as can be made between the various members of the several sections.

The till interbedded with gravel in the upper parts of these exposures is less oxidized and appears fresher than the till exposed in the lower thirty or forty feet of the bluff where gravel is not found. In the lower ends of several of the gullies toward the north end of this bluff, the Nebraskan drift is exposed (page 422).

At several places in the exposures described above the interbedded gravel contains such a great number of clay-balls that they constitute a very important part of the whole. These clay-balls indicate that the material had not been carried far before deposition, for clay material could not have withstood the wear incident to long transportation, even though it was firmly frozen. As the clay-balls were formed probably near the edge of the ice-sheet, their presence indicates the nearness of the ice-front at the time of gravel deposition.

The banks of the creek valley in section 24 of Cedar township, Cherokee county, east of Larabee, show a number of small exposures with gravel and sand associated with the till. Examples appear a few rods to the north and to the south of the east-west quarter-section line. Farther down the creek valley, exposures of gravel, sand and silt associated with till may be seen at a number of places. Some of these gravels evidently are included masses, while others may be gravel beds of some extent. A conglomerate ledge projects at one place, and elsewhere masses of conglomerate lie on the surface. The valley slopes are quite completely grassed over but if good exposures existed, the section might be somewhat similar to that of the Mill creek bluffs described above.

A peculiar case of interbedding of gravel and till or really of inclosure of a layer of till in a great gravel deposit is exposed in the pits of the Cherokee Sand and Gravel Company about half a mile northeast of the Mill creek bluffs just described. These pits are located in the northeast quarter of the northeast quarter of section 14, on a terrace of the Little Sioux valley about seventy-five feet above the river. Several pits have been worked in the past on the slopes of a ravine that cuts into the terrace, but at present a single pit is operated on the terrace and in this the gravel is removed to a depth of fifty to sixty feet. All the pits show essentially the same succession. At the top is a gravel bed a few feet thick; then a layer of till four to seven feet thick; and below this is the great gravel layer.

Three abandoned pits each seventy-five to a hundred yards from the others, are located on the slopes of the ravines as shown in figure 52. The till layers of the three exposures are of practically identical material, are at approximately the same

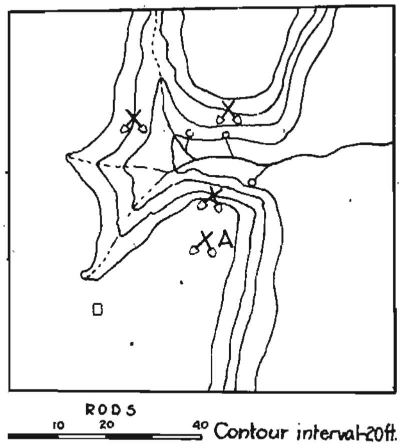


FIG. 52. Sketched contour map showing the location of gravel pits on the farm of F. R. Turner (northwest quarter of the northeast quarter of section 14, Cherokee township). The pit *A* is now operated by the Cherokee Sand and Gravel company.

altitude and have the same thickness, so that there is little doubt that the till was once continuous across the intervening valleys over an area at least 100 yards across. The mass is too large to have been floated in by ice and must have been laid directly by the ice-sheet. The till bed is thinner in the pit on the terrace just south of the ravine and is said to be absent beneath the terrace a few rods farther south.

The till of this horizon has a brownish gray color with iron staining along the joints. It is the fresher phase of the Kansan till, the type commonly found in association with gravel.

The position of this gravel beneath the bench of the Little Sioux valley would seem to prove that it belongs to the valley gravels but the presence of the clay-balls and this great mass of till indicate that the gravel was deposited during the Kansan ice-epoch.

A cut on Spruce street, just east of Second street, in the north part of Cherokee, within the area of the higher bench level, shows a great diversity of material including gravel, sand, bowlders and till layers. There are many alternations of the material horizontally and vertically. The gravel is coarse, dirty, and contains many large bowlders. Clay-balls are abundant, and in some horizons there is only a little gravel as matrix between the large clay masses. One bed appeared to be till, but when it was dug into, the material separated into rounded masses of till which are packed together without matrix. Also there are lenses or layers of till, too large to have been floated in, which must have been deposited directly by the ice. The upper seven or eight feet of the cut shows the more common valley gravels overlain by loess.

At various other places, examples of gravel layers interbedded with the till were seen, which indicates that the phenomenon may have a rather general distribution, but nowhere else are the interbedded layers known to be so numerous as in the Mill creek bluffs north of Cherokee.

ORIGIN.

The advance of the edge of an ice-sheet probably is really a succession of advances and retreats in which the advances are greater than the retreats. Likewise the general period of retreat of the ice-edge may be broken by temporary advances. Between these two general periods there is a longer or shorter time when the oscillations approximately balance each other, and the general position of the ice-edge remains nearly constant. These oscillations may be due to seasonal changes or to changes taking place over a longer period. Gravel deposited beyond the front of the advancing ice-sheet soon may be overridden by the ice, and covered with a deposit of till. If now the ice-edge withdraws temporarily, gravel may be deposited on top of the till only recently laid down. Readvance of the ice would result in a second till horizon, and so with several oscillations several alternations of till and gravel might be formed. It is not necessary to assume any great oscillations of the ice-front, for none of the gravel horizons noted above has been shown to cover any considerable area. An oscillation of a fraction of a mile, or a few miles at most, would be adequate.

Gravel deposited near the edge of the ice, in the way just outlined, would be of the outwash type, consisting of fresh, unweathered material with some pebbles of soft rocks, and would rest on fresh till. The gravel of these horizons is therefore interpreted as having been deposited just beyond the front of the ice-sheet during the minor oscillations within the stages of advance and retreat.

CHAPTER V

THE VALLEY GRAVELS.

Gravel deposits exist along many of the stream courses of northwestern Iowa. They are found in both large and small valleys; even in mere swales on the upland near the heads of small creeks. These deposits occupy broad, shallow valleys; are in most cases of only moderate thickness; and thin out toward the sides of the valleys. As a rule the present stream channels are cut into the gravel fillings, while the parts which remain form terraces which differ greatly in height, some of them being as much as 100 feet above the streams.

Nature of the Gravels.

The material is mostly coarse sand and fine gravel, and the extremes in either direction, coarse gravel or silty sand, are rare. The material is horizontally bedded, but not well assorted and the layers in most cases are ten to twelve inches thick rather than thin beds. Some of the layers are cross-bedded, with lens and basin structures. Another common condition, especially along small valleys, is thick layers of sand with small pebbles up to one or two inches in diameter scattered through it.

The material is distinctly fresh and commonly is without the least indication of iron-rusting or other alteration. Much of the sand, 70 to 80 per cent of the whole, is of pure quartz. Among the pebbles there are many kinds of rocks, but gray limestone pebbles are most abundant and give to the whole deposit a light color. The average of eighty-one analyses of pebbles from the valley gravels gives: Igneous rocks 36 per cent, of which 21 per cent are granite; and sedimentary rocks 64 per cent, of which 57 per cent are limestone. The percentage of the igneous and other resistant kinds of pebbles is larger down the valleys and to the west and southwest. In comparison with the material of the gravel hills, these valley gravels contain 11 per cent more of igneous rocks. This is perhaps the result of the destruction of the clay-balls and shale pebbles and a consequent relative increase of other kinds. The number of limestone pebbles worn out largely offsets the relative increase due to the destruction of the clay-balls, so that most of the increase is in the igneous rock pebbles.

Distribution and Description of the Valley Gravels.

Valley gravels are found along the larger rivers, along the medium-sized streams, along the small creeks even nearly to their heads on the uplands, and they fill in certain broad areas on the headwaters of some of the streams. Their distribution evidently is independent of the size of the valley.

Several of the larger rivers head northeastward within or along the Wisconsin drift-margin, and therefore may have carried drainage from the Wisconsin ice. This is true of Big Sioux, Rock, Little Sioux and Boyer rivers. The drainage basins of Floyd and Maple rivers, however, are entirely beyond the margin of the Wisconsin ice. Also many of the tributaries of those stream valleys which contain Wisconsin gravels, are entirely beyond the margin of the Wisconsin ice.

THE BIG SIOUX RIVER DRAINAGE BASIN.

The Main Valley.

Big Sioux river drained the east margin of the Dakota lobe of ice of the Wisconsin epoch from the head of the Coteau des Prairies southward to Canton, and received through its larger tributaries drainage from the west margin of the Des Moines lobe. The valley contains a gravel deposit south of the northwest corner of Iowa and at several places this deposit forms prominent terraces.

Near the northwest corner of the state, west and northwest of Granite (Plate XV), there is a terrace area two miles long and one-half to three-quarters of a mile wide (Granite terrace). The surface altitude is 1330 to 1345 feet above sea level, or eighty to ninety feet above the river. At the south end of the bridge on the west line of section 19 just west of Granite, the terrace gravel is twenty feet deep, and rests on Kansan till which continues down to the creek level, twenty to twenty-five feet lower. The north slope of the valley at this place shows twenty to twenty-five feet of fresh gravel and sand in the terrace. About a mile west of Granite in the northwest quarter of section 24, the Chicago, Rock Island and Pacific Railway Company operates a gravel pit in the terrace. The following section is exposed in the pit and in a gully below.

		FEET.
4.	Soil, etc	3
3.	Bowlder bed, badly iron-rusted and partly cemented. The coarse-grained bowlders of igneous rock are rotted, and the limestones are decayed to brown masses	4
2.	Relatively fresh gravel and sand	16
1.	Kansan till. Continuous exposure for 5 feet and at intervals for 30 feet	35

The gravel horizon in the two exposures noted has a thickness of about twenty feet, but these exposures are located along the continuation of Blood Run valley across the terrace, and the average thickness of the deposit over the whole area is probably less.

South of Blood Run the terrace continues as a narrower belt across sections 26 and 35 and is terminated by an eastward bend of the river just south of the township line. It begins again in section 7, Centennial township, and with a width of about a mile continues south to Klondike (Klondike terrace). The Klondike terrace is only forty-five to fifty-five feet above the river or thirty to forty feet lower than the Granite terrace. The material was seen just east of the bridge at Klondike, where it is a coarse gravelly deposit, and in the north part of section 17, where it is largely coarse gravel with bowlders, and is partly cemented. In the latter exposure the gravel rests on a tough dark drift which Professor Shimek has interpreted as "probable Nebraskan"[52].

From Klondike south to Canton the river follows the Iowa bluff, and the Dakota side, although rising gradually, does not present a distinct terrace. Along this portion of the Big Sioux valley the Dakota lobe of ice pushed up to the river and such gravel deposits as exist are probably of Wisconsin age.

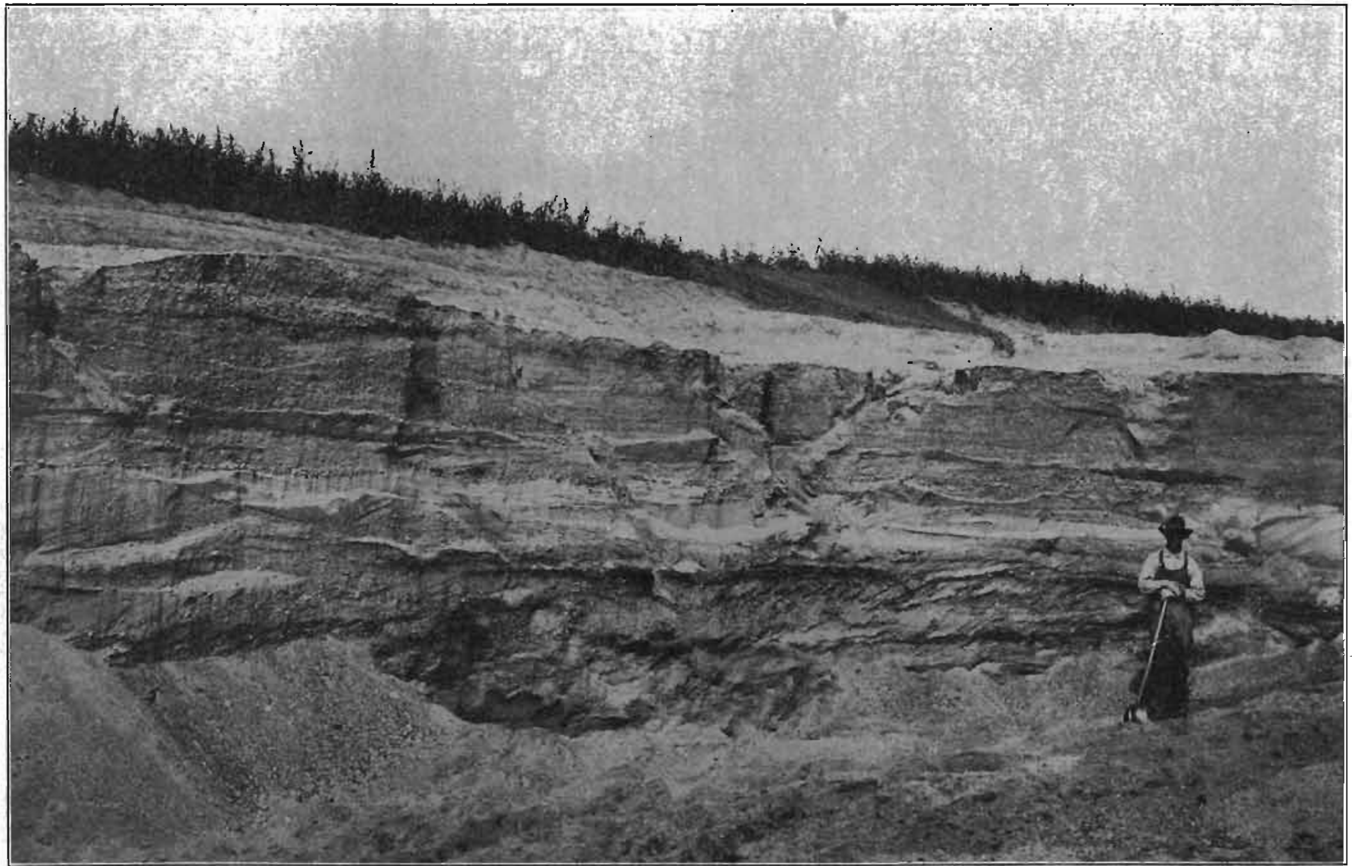
South of Canton, terraces appear at various places along the valley to Hawarden and Chatsworth. The river swings from side to side of the valley and the terraces are found here on one side and there on the other. The altitude of these benches is twenty to thirty feet above the river and is less southward.

Rock River Valley.

Rock river heads in northeastern Pipestone county, Minnesota, on the slope of the Coteau des Prairies. It enters Iowa at the center of the north line of Lyon county and flows southward and southwestward across Lyon and northwestern Sioux counties to Big Sioux river. Aided by its tributaries from the east it drained about fifty miles of the Wisconsin ice-margin and was therefore well located to receive gravel deposits of Wisconsin age. South of the state line the valley flat is about a mile wide, and much of this flat is a terrace about twenty-five feet above the river. Rock Rapids, Doon and Rock Valley are located on this terrace. At the mouth of Rock river valley the terrace unites with that of the Big Sioux, making a large level plain several miles across.

At Rock Rapids the gravel is twenty-five to thirty feet thick and rests on yellow Kansan till. A view of a pit about half a mile north of Rock Rapids showing cross-bedding and basin structure and variations in the coarseness of the material is shown in Plate XXI. At Doon the gravel deposits have been extensively worked in the past by the Great Northern Railway Company. A pit face here showed twenty-five feet of gravel, which was said to continue without

[52]Shimek, B., Pleistocene of Sioux Falls and Vicinity: Bull. Geol. Soc. Amer., Vol. 23, p. 144, 1912.



Lebatchka and Pattengill pit about half a mile north of Rock Rapids, Lyon county. The view shows cross-bedding and basin structure, variation in the coarseness of the material, and the thickness of the stripping. (Beyer, Iowa Geological Survey, volume XXIV, Plate XXXII, page 421.)

change for at least five feet below the pit bottom. At Rock Valley the town well is eighteen feet deep and is entirely in gravel, and the Chicago, Milwaukee and St. Paul Railway pit west of town has a depth of twenty feet, without reaching the base of the gravel. The material exposed at all these places along Rock river is fresh, and consists of sand and fine gravel with few cobbles or bowlders. Cross-bedding, inclined-bedding and basin structure are common.

TRIBUTARIES OF ROCK RIVER.

Area Northeast of Ellsworth, Minnesota.—East and northeast of Ellsworth, Minnesota, there is a slightly rolling area at the union of several small creeks. Gravel was seen in several shallow exposures where the roads cross the broad, saglike valleys, and north of Ellsworth there are pits four to six feet deep. This area is mapped on the Nobles county map of the Minnesota Geological Survey as "Modified Drift, Gravel and Sand"[53], but some of the area included is moderately rolling and certainly is not underlain with gravel. It is not an outwash plain completely covered with gravel, but an area with gravel along many of the small shallow valleys. The Wisconsin ice-margin lay about ten miles to the northeast, but the branches of Little Rock river and Kanaranzi creek completely prevented any drainage from the Wisconsin ice from reaching the Ellsworth area.

Little Rock River and Otter Creek.—Little Rock river, the principal tributary of Rock river from the east, heads in southern Nobles county, Minnesota, within and along the Wisconsin drift-margin, and therefore carried drainage from the margin of the Wisconsin ice-sheet. In Iowa it crosses the northwest corner of Osceola county and flows south and west across eastern Lyon county to its union with Rock river. There are gravel deposits along the valley at various places, forming indistinct benches which merge more or less gradually with the flood plain level which forms the major part of the area between the valley slopes. On the Lyon county map Professor Wilder showed this area as a Wisconsin gravel train with a width of about half a mile and extending continuously along the stream.

Just opposite Little Rock there is a low terrace with gravel exposures, and in the northeast part of the town is a small gravel pit. The material is horizontally bedded, and consists of fresh gravel and sand which is poorly assorted. The gravel of the pit is overlain by a two-foot layer of sandy, loesslike material which grades into the soil above. Although the valley may contain gravels of Wisconsin age, this and other deposits overlain by the loesslike material, along Little Rock river valley are older.

At George, ten miles below Little Rock, the terrace on the north side of the valley is almost half a mile wide and fifteen feet above the river. The south part of the village is on this terrace, and the town well, southeast of the railway station, has the following log.

	FEET.
4. Soil	3
3. Loesslike clay	7
2. Gravel and sand, very fresh	12
1. Yellow clay	?

Otter creek heads just within the Wisconsin drift-margin north of Bigelow, Minnesota, flows south along this margin for several miles and at the time of

[53]Upham, Warren, Geological and Natural History Survey of Minnesota, Vol. I, Pl. 22.

maximum glacial advance drained about ten miles of the ice margin. It has an irregular course southward across western Osceola county, and thence flows west and north in southeastern Lyon county to its union with Little Rock river southwest of George.

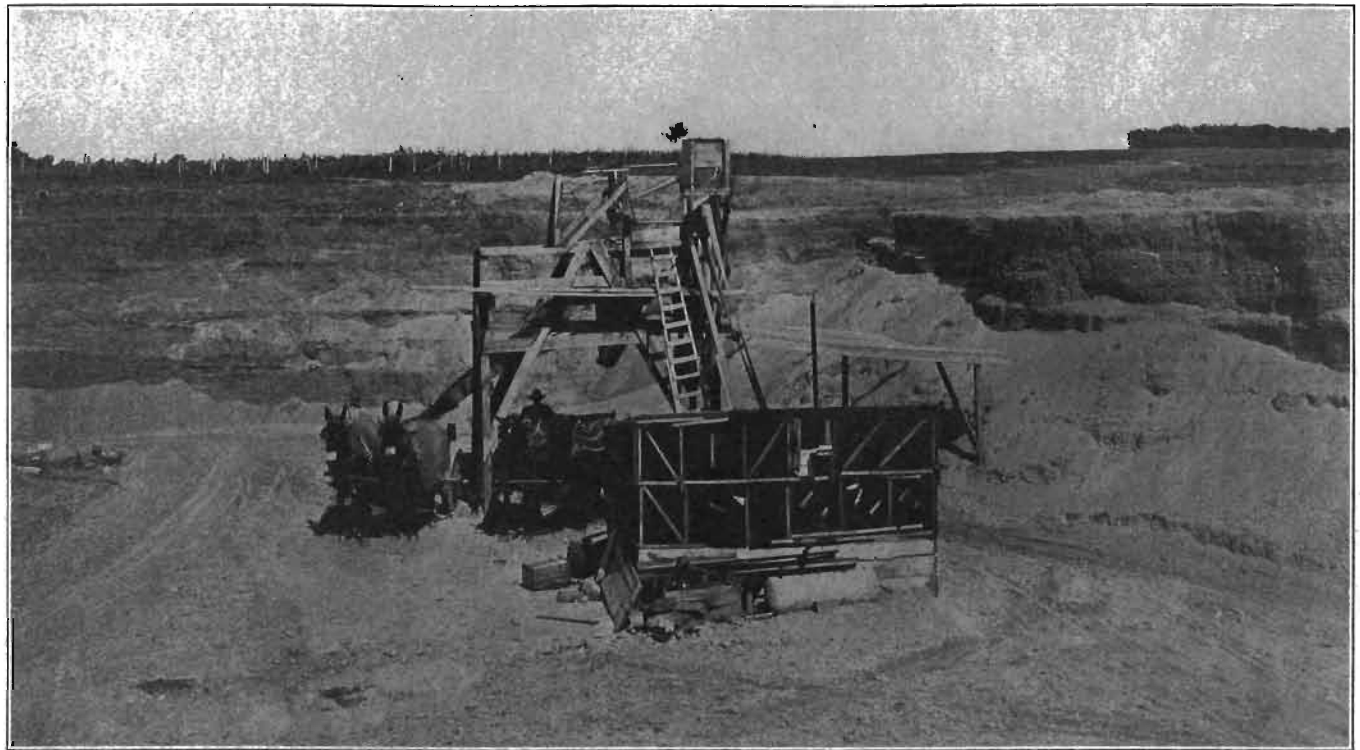
This valley has very little gravel in its upper course near the Wisconsin drift-margin, but from Gilman township in southwestern Osceola county across southeastern Lyon county gravel terraces are common. The material exposed in the terrace at Ashton is fresh, only the coarse-grained biotite granites being altered. An analysis of pebbles here showed the presence of 30 per cent of igneous rocks and 70 per cent of sedimentary rocks, 68 per cent of the latter being gray and buff limestones. On the county line northeast of Matlock, Otter creek valley is a broad shallow depression, with a broad flood plain and a narrower gravel terrace about fifteen feet above the stream.

Rat creek, a tributary of Otter creek in southeastern Lyon county, flows in a broad sag fifteen to twenty-five feet below the upland. The valley contains some gravel and indefinite low benches appear at several places. On the Lyon county map, Professor Wilder mapped a Wisconsin gravel train along the entire length of this creek. The valley is entirely beyond the Wisconsin drift-region and did not receive Wisconsin outwash.

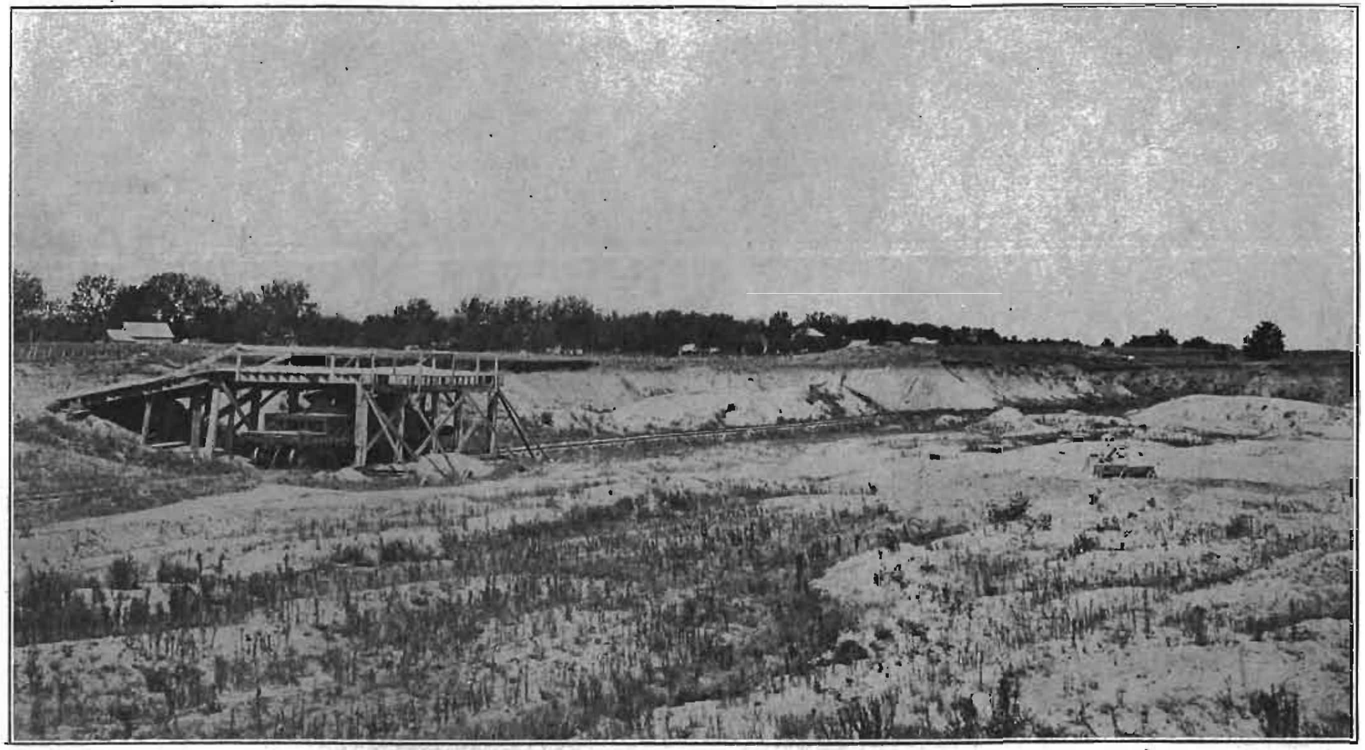
Area East and Southeast of Sibley.—At the edge of Sibley there are some large gravel pits in a deposit that is not along any present stream course. The deposit has an areal extent of eighty acres or more and underlies the east and south parts of Sibley. In the City pit (Plate XXII), twenty-five to thirty feet of gravel and sand were exposed, and the Chicago, Rock Island and Pacific Railway pit to the south (Plate XXIII) showed eighteen feet of gravel. The gravel rests on an uneven surface of fresh till, which at one place in the City pit slopes four feet in a horizontal distance of thirty feet, and greater irregularities are said to exist. Several mounds of till appear in that part of the railway pit from which the gravel has been removed. One of these, shown on the extreme right in Plate XXIII, consists of a mass of till with the gravel beneath it on at least one side, and in another the till has irregular contacts with the surrounding gravel, and may also be an included mass of till. The gravel of both pits is overlain by three to four feet of leached loess.

The gravel of these pits is, in general, fresh. At the top is a zone of coarse material, several feet thick, which is iron-stained, and near its base the gravel is in places stained a dark color. A well in this gravel area in the east part of Sibley stopped on a "cement rock" layer which is probably at the base of the gravel. Most of the dark coarse-grained igneous rock pebbles are decayed so as to crumble easily, limestone pebbles are abundant and unaltered, and many layers or laminæ contain a large percentage of grains of shale. The gravel is medium-grained and quite uniform. Bowlders are rare except at the base of the gravel, where they rest on the till. Several of these on the bottom of the pit are shown at the extreme left in Plate XXII.

A sewer pipe trench along the street just east of the City Park in the northeast part of Sibley was open in August, 1911, and showed at the south, sand and gravel overlain by loess. To the north fresh till rose above the level of the bottom of the ditch, the sand and gravel horizon thinned to zero, and the loess rested on the till. A sketch of this exposure is shown in figure 53. The exposure was apparently at the edge of the gravel deposit and showed the relation



City gravel pit at Sibley. This pit works twenty-five to thirty feet of gravel. The loesslike clay has been removed on the right. Its thickness, three to four feet, is shown in the center beyond the chute. (Beyer, Iowa Geological Survey, volume XXIV, p. 498.)



Chicago, Rock Island and Pacific Railway pit at Sibley. This pit shows fifteen to twenty feet of gravel and in most places has been worked to the underlying till. Mounds on this till surface or till masses in the gravel, which have been left behind in the process of excavation, are shown on the right at the far end of the pit. (Beyer, Iowa Geological Survey, volume XXIV, p. 499.)

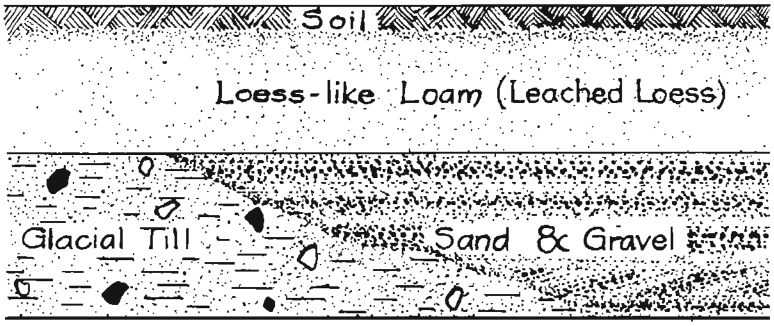


FIG. 53. Sketch of exposure in side of sewer pipe trench in the northeast part of Sibley. It shows the relation of the gravel horizon to the till, and of the loess to both the gravel and the till.

of the gravel to the till, and the relation of the loess to both the gravel and till. None of the contacts showed any alteration. Similar conditions were seen in an open trench along the north-south main street of Sibley at the street crossing near the Windsor Hotel (page 355).

Two miles southeast of Sibley, in the northeast quarter of section 30, East Holman township, a gravel pit, operated by the Chicago, Rock Island and Pacific Railway Company, exposed material similar to that at Sibley except that the upper part is coarser and more bowldery. Eighteen feet of gravel was exposed beneath a five foot zone of loesslike clay. A considerable area south of this pit in sections 30 and 29 is quite level, and is probably underlain with gravel. Sections 19 and 20 to the north, also are moderately level, but exposures in the gutter on the north of these sections show a yellow till.

The margin of the Wisconsin drift as traced by the writer is only a few miles to the northeast of these deposits east and southeast of Sibley, but the small valleys leading away from this Wisconsin drift-margin show no indication of having carried outwash material and the small valley of section 18, which passes near the deposit east of Sibley, did not head back to the margin of the Wisconsin ice. Also these deposits are overlain by loess which is older than the Wisconsin epoch. In appearance and composition these are the typical valley gravels of the Kansan drift-region.

Tom Creek.—This creek drains the northeast corner of Lyon county and enters Rock river at Rock Rapids. There are gravel terraces along its course and fresh gravel and sand may be seen in several valley pits in Midland township. A similar deposit is found along the north branch of Tom creek. Tom creek heads outside the Wisconsin drift-area and its gravel deposit is pre-Wisconsin in age.

Tom creek and Little Rock river drain the area in northeastern Lyon county mapped by Wilder as Wisconsin outwash (figure 27). Otter creek drains the similar outwash area in northwestern Osceola county. Although these areas have some gravel outside the present valleys, it is not sufficient to form an outwash plain. Several of the more important gravel deposits along these valleys are overlain with loess and probably essentially all of the gravel is of pre-Wisconsin age.

Mud Creek.—This creek heads in the southern part of Rock county, Minnesota, and flows south by southeast across Lyon county to Rock river near Doon. From the state line southward the valley is broad with gentle slopes and a flat bottom. This flat is, as a rule, a flood plain, but benches of gravel appear at many places. The altitude of the benches above the stream increases from ten feet near the state line to twenty-five feet near the mouth of the valley. The gravel is fresh and consists of relatively resistant material. Three analyses of pebbles from benches along this valley show an average content of 51 per cent of igneous rocks, which is 20 per cent higher than the average for pebbles from the valley gravels. The analyses also show a high percentage of quartzites and cherts, which are classed with the sedimentary pebbles. This valley is entirely within the Kansan drift-area and its gravels must be from reworked Kansan drift.

Small Tributaries of the Big Sioux.

None of the creeks considered under this heading are more than six to ten miles long and all lie entirely within the Kansan drift. The first of these south of the state line is Blood Run which flows southwestward across Sioux township in northwestern Lyon county, and joins the Big Sioux valley west of Granite. The Granite terrace of the Big Sioux valley (page 381) continues into the mouth of Blood Run valley as far as Granite, and gravel deposits appear to the east along the valley through sections 20, 21 and 22.

Plum creek enters the Big Sioux valley along the south edge of the Klondike terrace a few miles south of Blood Run. This creek was not followed, but Professor Beyer describes it as having a low indistinct terrace of small extent, and describes a pit exposure along the creek, three miles south of Larchwood, as showing seven to eight feet of clean sand and gravel resting on the blue clay.[54]

Dry creek and Six Mile creek, in western Sioux county, have broad, open valleys with narrow flood plains, and gravel deposits appear along them at various places, but nowhere do they form benches of any prominence. Similar gravel deposits are found along the creeks of western Plymouth county, especially along Broken Kettle creek, and in this region the gravel is overlain by a deposit which is unquestionably loess.

THE FLOYD RIVER DRAINAGE BASIN.

The Main Valley.

East of the Big Sioux lies the Floyd river basin. This is a smaller basin lying between the Big Sioux and the Little Sioux and is limited to the north by the spread of the basins of its larger neighbors. It heads in southern Osceola and northern O'Brien counties and flows south by southwest across eastern Sioux and central Plymouth counties to Missouri river at Sioux City. The Floyd drainage basin is separated from the Wisconsin drift-area by the high divide of southern Osceola county, and certainly received no drainage from the Wisconsin ice. However, the valley contains gravel from near its headwaters to LeMars, and probably to its mouth.

In northwestern O'Brien county there are small benches in the Floyd valley ten to twenty feet above the stream. Exposures in these benches are not

[54]Iowa Geol. Surv., Vol. XXIV, p. 426.

common, but one on the west side of the valley on the north line of section 21, Floyd township, showed three feet of horizontally bedded gravel overlain by about eighteen inches of leached loess.

About one mile north of Sheldon on the south side of the Floyd valley there are a large abandoned gravel pit and some smaller pits that are now being worked. In the abandoned pit west of the railway the following section was exposed.

	FEET.
3. Black soil	1½
2. Brownish yellow noncalcareous loesslike clay containing a few pebbles	3-5
This member grades into the soil above, and in some places, by the inclusion of pebble bands, it grades into the gravel bed below. Although not true loess in the lithological sense, this material is certainly the time equivalent of the loess. Loess exists in the vicinity and rests on the till, as may be seen in a railway cut between these pits and Sheldon (page 354).	
1. Sand and gravel horizon	10
This gravel is fine-grained with a few bowlderets, and some of the sand layers show inclined laminæ. The material of the layers changes horizontally in short distances so that any section taken fits only that particular place. The base was not exposed at the pit face but part of the floor of the pit is a cemented zone of cross-bedded sand.	

In a small pit just north of the large abandoned pit, the gravel rests on fresh brownish yellow Kansan till, and there is no cemented zone at its base. A pit on the east side of the railway showed twelve feet of fine gravel. Several clay-balls (till) were found here, this being one of the few places where they were seen in the valley gravels.

South of Sheldon Floyd river has a broad, open valley with a gradually widening valley flat. Patches of terrace about ten feet above the flood plain exist at many places, and there are gravel pits in these terraces at Hospers, two miles north of Alton, at Alton, Seney and Le Mars (Plate XV). At the east end of the Chicago and North Western railway bridge at Alton some pits expose ten feet of gravel with thin layers of coarse sand, overlain by three feet of loesslike clay, which rises to an indistinct bench twenty feet above the river. Other pits in a bench of similar height north of the railway station show the same loesslike zone overlying the gravel.

A pit near the river in the northwest part of Le Mars showed the following section:[54a]

	FEET.
5. Sandy black soil	4
4. Loesslike clay, leached	3½
3. Unleached loesslike clay with thin layers of sand	6½
The upper part of this zone contains small calcareous concretions.	
2. Gravel	3
1. Sand with thin layers of silty sand, exposed	3

The calcareous material removed by leaching from zone number 4 has been concentrated in the upper part of zone number 3 in the form of concretions.

[54a]This or a pit nearby was described and figured by H. F. Bain in his report on Plymouth county. Iowa Geol. Surv., Vol. VIII, p. 338 and Plate 29, figure 2.

These two zones are the time equivalent of the loess of the upland and together form a horizon much thicker here than farther up the Floyd vally at Sheldon. From the pit of B. Erdman just west of the above, several limb bones and pieces of deer horns have been taken.

South of Le Mars the flat of the Floyd valley is a mile to a mile and a half wide but it is all essentially at flood plain level. This flat is probably underlain with gravel.

Deep Creek Valley.

At Le Mars Floyd river is joined by Deep creek, which rises in southwestern O'Brien and southeastern Sioux counties, flows south to Remsen and thence west to Floyd river. Fresh sand and fine gravel appear in benches along this creek and exposures were seen in every section from Remsen to Le Mars. The gravel horizon is overlain by yellow loesslike clay, as in the Floyd river valley. In the northwest quarter of section 5, Marion township, the terrace is thirty feet above the creek, and a well on the terrace goes forty-five feet into sand, or fifteen feet below the stream level, without reaching the bottom of the sand.

A pit in the northeast quarter of section 4, Marion township, operated by C. H. Grimes, gave the following section:

	Feet.
4. Leached loesslike clay	3
3. Unleached loesslike clay with a few bands of pebbles in the basal part	3
2. Gravel	3
1. Sand and gravel, above water level	6

The pit is worked by a suction-dredge to a depth of about twenty feet below water level. The material is sand and fine gravel with some cobbles. Several vertebræ and other bone fragments have been pumped up with the gravel.

In the lower course of Deep creek valley just northeast of Le Mars there are two pits from which gravel has been dredged beneath water level. One is located in the northeast quarter of section 10, and the other a mile farther west in the northeast quarter of section 9. The pit in section 10, now abandoned, showed the following exposure above water level:

	Feet.
4. Soil, passing downward into yellow sandy clay	6
3. Alternating layers of fine sand and clayey sand, horizontally bedded and laminated	4
2. Brownish loesslike clay with thin partings of sand. What are apparently rootlet impressions penetrate this clay and iron-staining has taken place along these openings	6
1. Fresh fine-grained gravel with a few bowlderets 4 to 8 inches through; above water level	10

This pit can be worked to a depth of forty-seven feet below water level, where a layer is struck that is said to consist of flat, slabby pebbles, too hard to be penetrated by the dredge scoop. The material from this pit is fine sand with very little gravel. Details of stratification are of course unknown. At a depth of twenty-five feet a silty layer with stems and vegetable material is passed through. This was penetrated over the entire pit area, which is fifty to sixty yards across.

The pit in the northeast quarter of section 9 shows the following section above water level:

		FEET.
4.	Sandy dark soil	3
3.	Sandy dark gray clay, leached	4
2.	Unleached loesslike clay, containing thin layers of fine sand. This is the usual material overlying the gravels but is here thicker and more sandy than common.	15
1.	Fine gravel and sand, above water level	5

Gravel is dredged from this pit to a depth of thirty feet below water level. At this depth a layer of slabby pebbles is struck as in the other pit. Prospect drill-holes have been sunk near by, one of which penetrated fifty-eight feet of gravel below water level. As in the pit farther east, there is, at a depth of twenty to twenty-five feet, a dark silty layer containing vegetable material.

A number of bones have been dredged up from these pits, but no evidence could be obtained as to the horizon from which they came (page 409). They are not greatly altered and have a more modern appearance than bones from the Aftonian deposits of western Iowa farther south.

Deep creek is entirely in the Kansan drift and the explanation of its deep gravel deposit is a rather difficult problem. The valley in which the gravel lies apparently goes through the glacial drift, at least in part, for an exposure of Cretaceous rock exists near the level of Deep creek in the southwest part of section 2, less than half a mile up the valley from the abandoned pit in section 10, where the gravel was worked to a depth of more than forty feet below the creek level. Does this deep valley continue down Floyd river to the Missouri? When was the valley eroded, and when was it filled with gravel? Much more evidence concerning these gravel deposits is required before a satisfactory explanation can be given. Six analyses of pebbles from the gravel deposit of Deep creek valley show an average content of 48 per cent igneous rocks, which is about 12 per cent higher than the average for all analyses made of the valley gravels.

THE LITTLE SIOUX RIVER DRAINAGE BASIN.

This, the largest of the southwestward flowing streams of western Iowa, drains about 3600 square miles (about half) of the area under discussion. In common with its chief tributary, the Ocheyedan, it heads on the Wisconsin drift-plain, and after leaving it near Milford in Dickinson county, it flows near the Wisconsin drift-margin south to the mouth of Brooke creek in northwestern Buena Vista county. It received the drainage of the Wisconsin ice-front from a point east of Sibley to Storm Lake, a distance of 100 miles, and at the present time drains more than a thousand square miles of the Wisconsin drift-plain.

The Headwaters of the Little Sioux above Spencer.

The Little Sioux river system above Spencer consists of the Little Sioux proper, the Ocheyedan with its tributary the Little Ocheyedan, and Stony creek, all of which have their upper courses within the Wisconsin drift-region. Along the upper courses of the Little Sioux there are a number of isolated gravel deposits. West of Montgomery in section 29 of Diamond Lake township, Dickinson county, there is an indistinct terrace on the west slope of the valley twenty feet above the stream, consisting of sand with pebbles scattered through it. The pebbles are better rounded than is common for the valley gravels and quartzite is more abundant. A low gravel bench is found also along the lower course of the West Branch of Little Sioux river, and at the union of the two branches in section 7, Lakeville township. In the south part of Lakeville township, terrace remnants along the Little Sioux are more common, and one which begins in the southwest quarter of section 21, thirty feet above the river, can be traced southward across sections 28 and 33, to the township line, where it is forty feet above the river.

In section 33, Lakeville township, a higher bench stands seventy-five to eighty feet above the river, and continues into northern Okoboji township to the margin of the Wisconsin drift where it has approximately the altitude of the Milford bench (page 276). Thick deposits of gravel underlie this bench in the northeast quarter of section 4, where they are seen to rest on till that apparently is Kansan, and copious springs issue from the base of the gravel.

The Okoboji outlet, which drains the lakes of northcentral Dickinson county, joins the Little Sioux southwest of Milford. This course was the outlet of enormous floods of water during the Wisconsin ice-epoch and great gravel deposits appear along it. The extent of this gravel area is shown in figure 31, page 273. At Milford, which stands on this gravel flat, the deposit is twenty to twenty-five feet thick; in the west part of section 12 there are cuts eight to ten feet deep in gravel; and in the southeast quarter of section 11 the south slope of Okoboji outlet shows a gravel stratum forty-five to fifty feet thick with cemented conglomerate layers near the water level. In the southwest quarter of section 12 and the northwest quarter of section 13 the Chicago, Milwaukee and St. Paul Railway Company has excavated great quantities of this gravel for railway ballast. The thickness of the gravel is ten to twenty feet and it rests on blue clay. The gravel of this bench is coarser and more rusty than is the gravel of most of the deposits that are beyond the reach of the Wisconsin ice drainage. Eight analyses of gravels from the Little Sioux valley between the Wisconsin boundary and Spencer show an average of 41 per cent of igneous rocks, which is about 5 per cent higher than the average igneous content of gravels found in valleys that could not have received drainage from the Wisconsin ice.

This gravel area extends as a terrace down the Little Sioux valley to the county line and south to Spencer. At Milford the terrace is seventy to eighty feet above the river, but it declines to fifty feet at the county line, and to twenty feet at Spencer, as shown in figure 54. In this distance the river falls seventy feet while the terrace drops about 120 feet. The fall of the terrace measured along the center line of the filled belt is six and two-thirds feet per mile, and the fall of the river along this same line would be about four feet per mile.

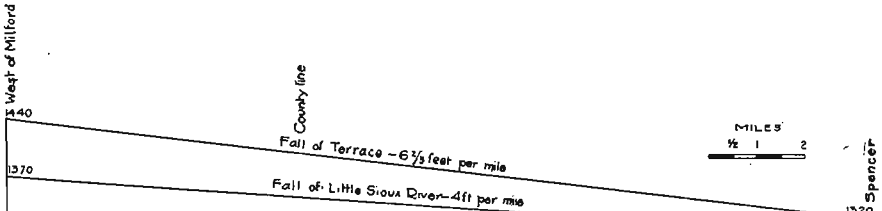


FIG. 54. Profiles along the Little Sioux river valley from west of Milford to Spencer, showing the gradient of the river and the gradient of the terrace. The distance is measured along the central line of the gravel-filled area.

The fall of the river from west of Milford to Spencer, measured along its winding course, is two and two-thirds feet per mile.

In the pits south of Milford the gravel is overlain by two to three feet of brown sandy noncalcareous material with few pebbles. It is not the usual leached loess but bears some resemblance to it and, considering the location of the region, where the loess is almost absent on the upland, this may be the equivalent of the loess. Such an interpretation of the overlying material would make the gravel of the Milford bench pre-Wisconsin, and place it with the valley gravels of the Kansan region. The more rusty character of the gravel, the location of the deposit with respect to the Wisconsin drift-boundary, and the decline of the bench southward to stream level at Spencer seem to separate this gravel deposit from the usual valley gravels and it is most probably Wisconsin outwash.

The upper twenty-five to thirty miles of Ocheyedan river is within the Wisconsin drift-area, and in this part the valley contains very little gravel. South of the Wisconsin drift-boundary in Harrison township of Osceola county and southeast to Spencer, Ocheyedan river has a broad flat, underlain with gravel, but its altitude is little if any above the flood plain.

Stony creek heads within the Wisconsin drift in western Dickinson county. South of the boundary it has a flat one-half to one mile in width, much of which is a low terrace ten to fifteen feet above the creek. Farther south in northwestern Clay county the terrace is absent and the flat is less prominent, although the valley remains broad and open south to its union with the Ocheyedan.

The valley flats of the Ocheyedan, Stony creek and the Little Sioux all unite in Riverton township west of Spencer in a large gravel area (Spencer flat) which extends from Everly eastward through Spencer to the southward bend of the Little Sioux southwest of Dickens. It covers the north half of Riverton township, a strip about two miles wide across Sioux township, and continues west and north up the Ocheyedan and Little Sioux valleys. Probably more than half of this area is a terrace fifteen to twenty feet above the river. Gravel exposures appear at many places. At the pit of the Spencer Cement Tile Company, the gravel is worked to a depth of about twenty feet by a suction-dredge which pumps the gravel from beneath ground-water level. About ten feet of material is exposed above water level, and this consists of cross-bedded fine gravel and sand. Blue clay is said to underlie the gravel and bowlders have been encountered toward the base of the gravel. The gravel is overlain by a brown sandy material similar to that over the gravel at Milford.

Tributaries of the Little Sioux from the East Between Spencer and Brooke Creek.

East of Spencer the Little Sioux is joined by Meadow brook, which with its several branches drains those parts of northeastern Clay and southeastern Dickinson counties which lie within the Wisconsin drift-boundary. Small gravel deposits are present along this creek at many places, but not in quantities sufficient to form terraces. Five miles east of Spencer the Little Sioux is joined by the outlet of Lost Island lake (Dickens outlet), and there are considerable gravel deposits along this valley south and southeast of Dickens (Plate XVI, page 268).

Through eastern Clay county and northern Buena Vista county west as far as Linn Grove, the Wisconsin drift-margin lies along or near the east bluff of Little Sioux river and no tributaries of importance enter from the east in this distance. Elk creek, entering at Gillett Grove in southeastern Clay county, has very little gravel along its course, although it drained about six miles of the Wisconsin ice-margin and now drains probably a township of Wisconsin drift-plain. Brooke creek, which flows north along the Wisconsin drift-margin to the Little Sioux, drained eighteen miles of the Wisconsin ice-margin. It has little gravel in its upper course, in Washington and Elk townships, but in its lower course, in Brooke township, there are thick gravel deposits into which the creek and its tributaries have cut deep, narrow valleys.

THE GRAVELS OF THE LITTLE SIOUX VALLEY FROM SPENCER TO ITS MOUTH.

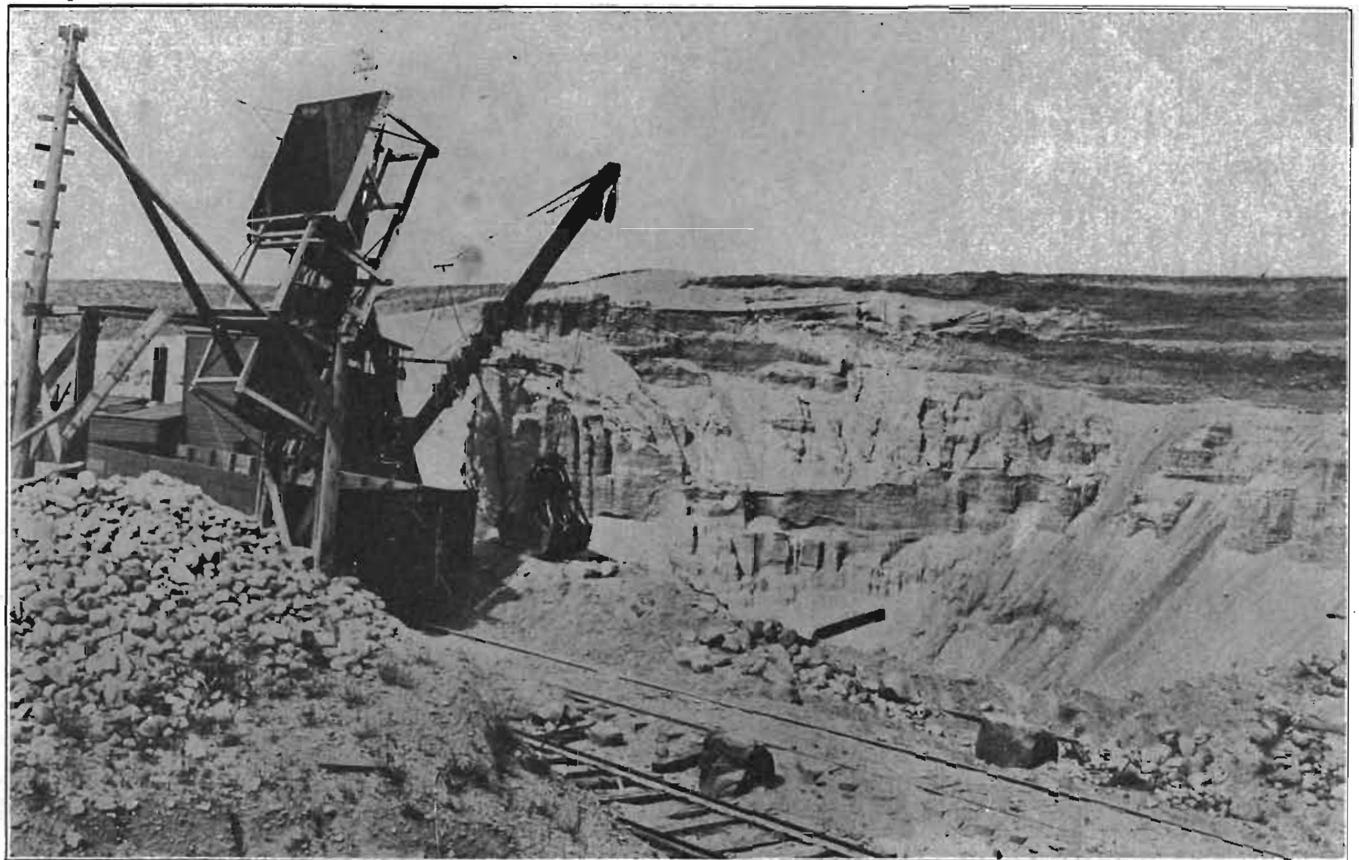
From the bend east of Spencer south to Gillett Grove Little Sioux river flows through a narrow valley and there are practically no gravel deposits. Below Gillett Grove, in Herdland township, there are some small gravel terraces, chiefly along the east slope of the valley, which here marks the Wisconsin drift-margin. At Sioux Rapids the station of the Minneapolis and St. Louis Railway is on a bench about fifty feet above the river and a gravel pit just north of the railway station shows twenty feet of gravel. To the west there are benches at several places, usually on the inner side of the great bends of the valley. There are in places one, in places two, and in places three benches, and their altitudes above the river differ greatly. One common elevation is forty-five to sixty feet above the river.

At the bend of the Little Sioux in southeastern O'Brien county, at the mouth of Waterman creek, there are gravel benches about one hundred and fifteen feet above the river, and only fifteen to twenty-five feet below the adjoining upland. A gravel deposit at this level on the west line of section 23, Waterman township, has a thickness of thirty feet. This terrace continues up Waterman creek valley and up Murry creek valley to Sutherland.

South of the bend and in Cherokee county two bench levels are common; one near the upland, 100 to 120 feet above the river, and another fifty to fifty-five feet above the river (figure 55). In Spring township the higher terrace is found on the north line of section 2; in the southeast quarter of section 17; in the west half of section 29; and at the lower ends of the valleys which enter in sections 16 and 19. The lower terrace is found in sections 3, 2, 9, 16 and 29, and as a large area in sections 17, 20 and 30. At many places this terrace grades down to the flood plain.

In Cherokee township the higher terrace is found in section 13, along the lower course of Mill creek, and southward to and through Cherokee. Lower terraces of considerable area are found north and south of Cherokee, and the town of Cherokee stands on such an area. There seems to be very little uniformity in the altitude of these benches.

In section 14 there are two pits in the terrace, which is here about seventy-five feet above the river, that go down into the deposit fifty and sixty feet respectively. The material is sand and gravel, with a few bowlders. Clay-balls are abundant locally. The material is relatively fresh, but releases an irony dust when it is displaced. The pit of the Cherokee Sand and Gravel Company is sixty feet deep, and the bottom is on a bowlder zone which is said



Gilleas pit in section 14, Cherokee township, Cherokee county. This is one of the largest exposures known in the region. The pit is worked by a steam clam-dipper to a depth of sixty feet below the terrace level. (Beyer, Iowa Geological Survey, volume XXIV, p. 157.)

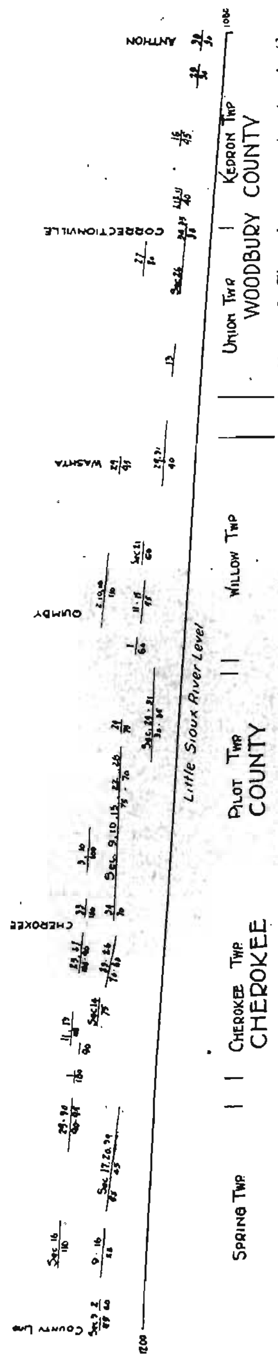


Fig. 55. Sketch showing altitude of benches along the Little Sioux river valley from the north line of Cherokee county to Anthon in Woodbury county.

to rest on 'blue clay". About eighty rods south of this pit is the Gilleas pit which shows a face fifty to sixty feet high, made up of layers of coarse and fine gravel and sand. A view of the Gilleas pit is shown in Plate XXIV. There are many cobbles and bowlderets in this pit, and some very large bowlders. On the basis of the evidence given elsewhere (page 378) the gravel of these pits is not included with the valley gravels but is believed to have accumulated during the Kansan ice-epoch.

Just south of Cherokee the Illinois Central Railway Company has removed the gravel from an area of several acres. An exposure in the east end of this pit showed Kansan till below about twenty feet of gravel.

In Pilot township the most continuous terrace is seventy to seventy-five feet above the river, but other altitudes are represented. At Washta the lower terrace is not over forty feet above the river, and the upper one is ninety-five feet above water level (figure 55). At Correctionville the terraces are still lower, being thirty and eighty feet above the river. Correctionville stands on the lower terrace and the higher one is represented by benches at the mouth of and within the valley of Pierson creek.

The lower terrace is found in Kedron township south of Correctionville, where there is a pit on the west line of section 15; at Anthon where it is thirty feet above the river; and in sections 17 and 18 of Miller township, three miles south of Anthon. Farther south terraces were not recognized, and practically all of the flat is flood plain, at an elevation of twenty to twenty-five feet above the river.

The upper bench level was not positively identified south of Correctionville, but masses of gravel were seen at several places high up on the slopes of the valley. In the southwest quarter of section 20, Miller township, there is some altered gravel eighty-five feet above the river; opposite Oto in section 5 there is a gravel deposit about a hundred feet above the river; and in section 8 there is an exposure of sand eighty to ninety feet above the river. These materials are all altered and do not look like the deposits found north of Correctionville.

Since Little Sioux river drains so large an area of Wisconsin drift, it should have carried much Wisconsin drainage and much gravel along its valley should be of corresponding age. If the course westward across the great watershed is a Wisconsin glacial diversion, then the gravel benches in this part of the valley must be of Wisconsin age. The high bench beginning in southeastern O'Brien county and continuing southward is continuous with benches in valleys that did not receive Wisconsin gravels. Also the gravel of this high bench is overlain by loess in the north part of Cherokee (page 351), in the southwest part of section 31, Pilot township, and at a few other places along the Little Sioux valley and at many places along the courses of the tributary valleys. This upper terrace is therefore preloess in age. The lower terraces are not so definite as to loess covering but the gravel of these, except in the narrow part cut during the Wisconsin time, may also be of pre-Wisconsin age.

MAIN TRIBUTARIES OF THE LITTLE SIOUX FROM THE WEST BELOW SPENCER.

None of the tributary valleys of the Little Sioux from the west, south of the Ocheyedan, which enters at Spencer, received drainage from the Wisconsin ice, and yet these valleys in Clay, O'Brien and Cherokee counties contain prominent gravel deposits, which continue in some cases to the heads of small valleys, whether they head northward, or to the east or west toward some of the interstream divides.

Willow Creek.—The first creek of importance which joins the Little Sioux from the west, south of Spencer, is Willow creek. Along its lower course in section 7, Herdland township, there is a fresh gravel deposit covering a large area and forming benches about thirty feet above the creek and thirty-five to forty feet above Little Sioux river. An analysis of pebbles showed the presence of 72 per cent of sedimentary rocks, all of which were limestone. These gravels are too far from the mouth of the valley to have washed back from the Little Sioux, and therefore are not of Wisconsin age.

Waterman and Murry Creeks.—In its upper course the valley of Waterman creek, which drains eastern O'Brien county, is a broad sag fifteen to twenty feet below the general level, but it deepens within a short distance, so that in its lower course it is more than 100 feet below the upland. In western Omega township there is a gravel bench fifteen to twenty feet above the valley bottom, and gravel extends down to water level. The altitude of this bench above the stream increases very much to the south so that in central Grant township it is seventy feet, and near the mouth of Waterman creek, more than a hundred feet above the stream. Here it unites with the high-level bench of the Little Sioux valley. The relation of the slope of the terrace and the gradient of the creek is shown in figure 56. In Grant and Waterman townships the terraces have considerable area and the gravel in most of them is twenty to thirty feet thick. Waterman creek and its tributaries have cut narrow, steep-sided valleys in the gravel-covered area, leaving level-topped spurs extending out toward the creek from either side and making a very rugged topography. The gravel material is very uniform, consisting of fine gravel with pebbles and small bowlderets. The sand is coarse or medium-grained, sub-angular and the larger grains are dominantly limestone and the smaller grains dominantly quartz.

Murry creek is a tributary of Waterman creek. It heads on the east slope of the high divide of O'Brien county, a mile north of Sutherland and flows south of east to Waterman creek. Its entire length is only eight to nine miles.

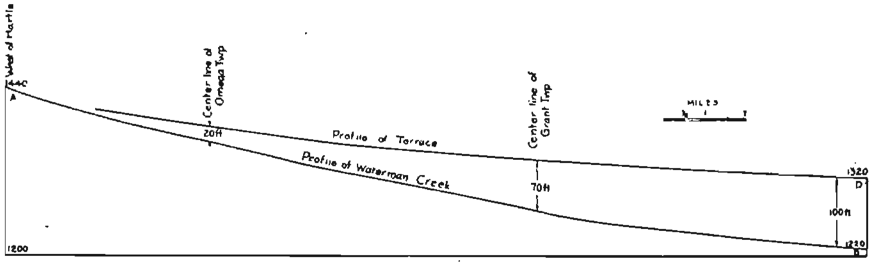


FIG. 56. Profiles along Waterman creek valley from west of Hartley to its mouth, showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

Along its upper course at Sutherland there are several gravel pits exposing ten to fifteen feet of fresh gravel which rests on glacial till and is overlain by two to three feet of loesslike clay (leached loess). At Sutherland the gravel terrace is only fifteen feet above the stream but to the east its altitude is greater as the stream descends, until at the mouth of the creek the terrace merges with the high-level benches of the Waterman and Little Sioux valleys at 110 feet above the valley bed. The terrace in this distance drops 100 feet while the stream drops 200 feet. The slope of the terrace and the gradient of the stream are shown in figure 57.

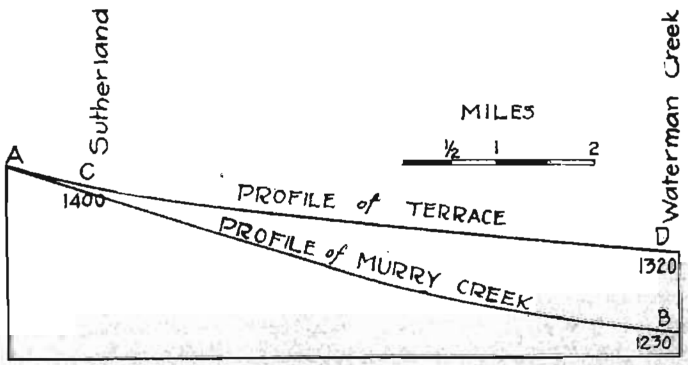


FIG. 57. Profiles along Murry creek valley from Sutherland to its mouth, showing, A—B, the gradient of the creek, and, C—D, the gradient of the terrace.

This valley furnishes one of the best examples of the way the gravels exist in small valleys well out on the upland only a mile or so from the head of the stream. It furnishes very positive evidence against the hypothesis of overwash from the Wisconsin ice-margin to the north. The stream heads on a north-south divide and numerous streams flowing to the east and west drain the divide farther north. If water could have passed over the high divide south of Ocheyedan river, it would have been carried away either to the east or west by some one of a dozen valleys to the north of Sutherland. The altitude of the gravels at Sutherland is 1415 to 1420 feet above sea level. They are on the slopes of the highest watershed of northwestern Iowa.

Mill Creek.—Mill creek, with its tributaries, drains central and southern O'Brien county and central northern Cherokee county. The territory which it drains in its upper part is quite level but farther south its basin is more rolling, so that in northern Cherokee county it is rather rugged. Mill creek did not receive drainage from the Wisconsin ice, for its headwaters are all south of the high divide of southern Osceola county and their gathering grounds are limited on the north by the headwaters of Floyd river and Waterman creek. However, the valleys of Mill creek and its tributaries contain gravel, which in many cases extends nearly to their heads on the upland. This applies to creeks heading east and west on the inter-valley divides as well as to those heading northward.

Three miles west of Primghar several branches of Mill creek unite, and at their union there is an almost level area covering several square miles which appears to be underlain with gravel. The area is not absolutely flat but rises gradually away from the creek and its boundary is in some places quite indefinite. It has an altitude of about fifteen feet above the creek but is not a definite terrace. Projections of this area extend up stream courses to the northwest, north and northeast, and it continues south beyond the center of Dale township. Wells near the quarter-corners on the south of section 33, and the east of section 32 are sunk twenty feet in sand and gravel and one at the quarter-corner on the south of 29 is said to be forty feet deep and all in gravel.

An east branch of Mill creek heads about two miles northeast of Primghar and flows southwest through northwestern Highland and eastern Dale townships. In sections 6 and 7 of Highland township, only a few miles from its head, this valley contains a gravel deposit with distinct benches fifteen feet above the creek. Two gravel pits in these benches show seven to eight feet of fine gravel and sand, overlain by two to four feet of leached loesslike clay. The stream has cut through the gravel, exposing the till beneath. Benches are found farther down the valley through Dale township, as in the southwest corner of section 13, and at the northwest corner of section 26.

At Paullina in Union township the benches lie twenty to twenty-five feet above Mill creek, and there are numerous exposures of gravel along the main valley and in the lower courses of tributaries.

In section 28, Union township, there is a large exposure in a bench forty to forty-five feet above the stream. In part of the exposure the gravel apparently extends to the water level, but elsewhere it rests on greatly altered Kansan till at about ten feet above the stream. The material here is fresh fine gravel with much sand, and is overlain by three to four feet of loesslike clay. On the south side of the valley in the west part of section 34 the bench is about fifty feet above the creek (figure 58). The gravel layer consists of thirty-five to forty feet of fresh coarse sand with pebbles and bowlderets scattered over it. It is overlain by four to six feet of loesslike clay and overlies till which rises six feet above the stream.

Willow and Nelson creeks head in Liberty township north of Calumet, flow westward into Union township, turn southward, unite, and join Mill creek just

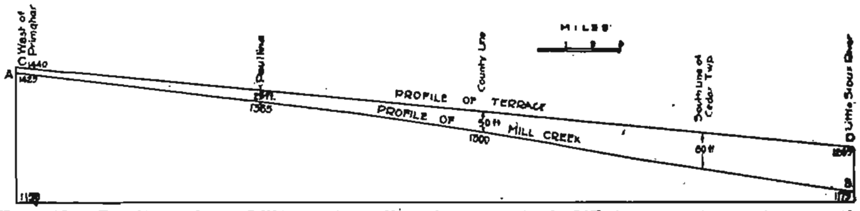


FIG. 58. Profiles along Mill creek valley from central O'Brien county to its mouth showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

beyond the county line. Willow creek has a number of gravel hills along its slopes in Liberty township (pages 365 to 367), but it does not have a prominent valley-gravel deposit. Below the turn to the south in eastern Union township gravel benches are common along these creeks, especially in sections 25, 26 and 36 in southern Union township. On the south line of section 24 a pit shows five feet of very fresh fine gravel, and a well on the bench along Nelson creek in the southwest quarter of section 23 penetrated twenty feet of sand and gravel. A low area connects Nelson creek valley in the west part of section 23 with Mill

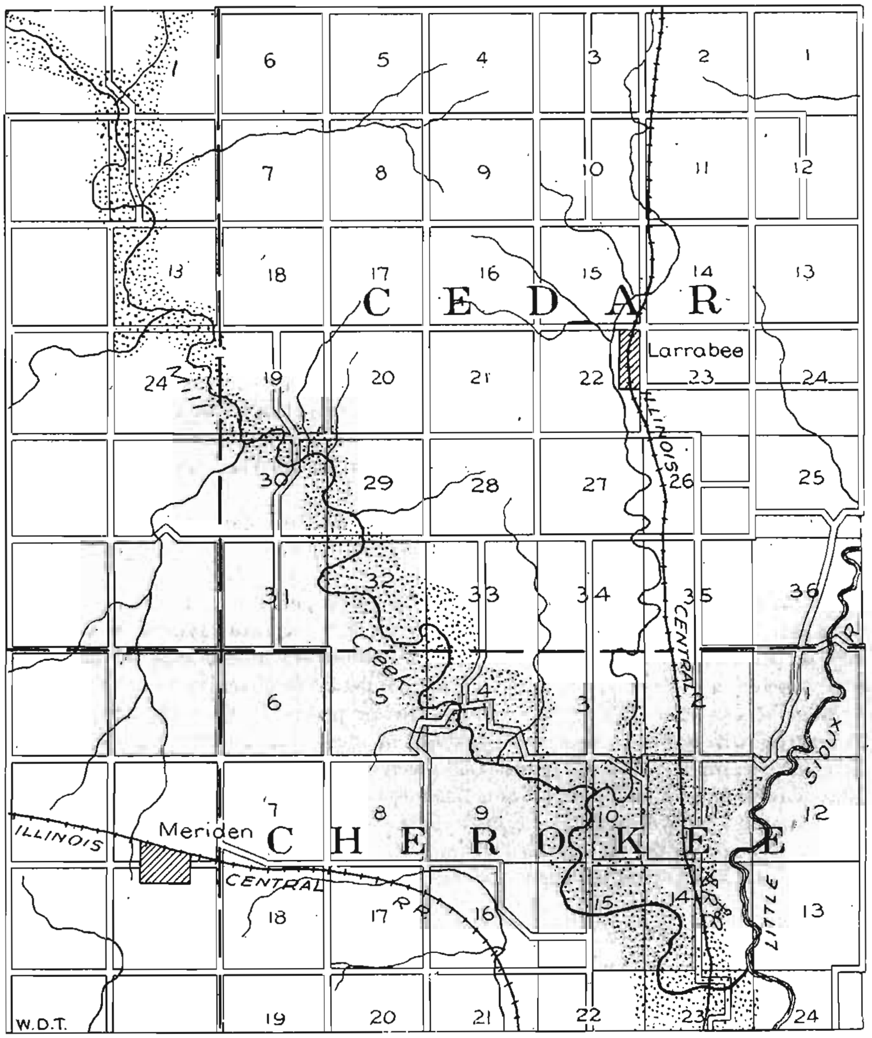


FIG. 59. Map of a part of northern Cherokee county showing by the shaded area, the original extent of the aggraded flat of Mill creek. Part of this area remains as terrace and part has been cut out and now exists as steep slopes or flood plain.

creek valley in the south part of section 15. It suggests an old water course, but the surface is undulating and does not appear to be underlain with gravel.

Farther south in Cherokee county the quantity of gravel material along Mill creek is larger although the benches have small areal extent and are by no means continuous. The original width of the aggraded flat, as shown in figure 59, was about a mile, but much of this area has been cut out and is now in steep slopes or narrow flood plain. The altitude of the benches above the creek is greater to the south, as is shown in figure 58, so that on the south line of Cedar township they are seventy-five to eighty feet above the creek and near the mouth of the valley they stand almost a hundred feet above the stream. The benches occupy alternate positions on the valley sides where the stream swings back and forth, and some of them are half a mile wide.

The Mill creek bench extends into the lower course of a tributary valley in the northeast quarter of section 10 and the east half of section 3, Cherokee township, and from this valley a prong of the bench extends southeast across the northwest quarter of section 11 to the Little Sioux bench (figure 59). At the time of maximum aggradation this prong separated an area of upland in the southwest part of section 11 and the northwest part of section 14 from the upland to the north.

MINOR TRIBUTARIES OF THE LITTLE SIOUX IN CHEROKEE AND WOODBURY COUNTIES.

Through Cherokee and Woodbury counties there are many small valleys, tributary to the Little Sioux, that have gravel in their lower courses. In general the benches of these valleys are continuous with those of the Little Sioux valley. In some cases the gravel may have been carried into the tributary valleys from the main valley, but in most cases it continues too far up the tributary valleys to have been derived in this way.

In section 11, Spring township, in the northeast corner of Cherokee county, a small creek enters the Little Sioux from the east, and in the northwest quarter of section 12, there are benches along this valley 105 to 110 feet above the creek. The material exposed is relatively fresh sand with pebbles, and seems to have a thickness of ten to twenty feet, and rests on till. A thin layer of gravel was seen on the slope of this valley near its head two miles farther east in the northeast quarter of section 7, Brooke township, Buena Vista county.

Most of the east half of section 16, Spring township, is a terrace 110 feet above the Little Sioux, and a projection of this extends east up this valley through section 15. The creek flowing southward through sections 19 and 18 of Spring township is bordered by benches sixty-five feet above the creek, and the gravel, which is twenty to thirty feet thick, rests on till. Gravel benches exist also along the valley in sections 24 and 25, Cedar township, especially in its lower part, where they become continuous with the bench of the Little Sioux valley.

In Cherokee township, there are gravel deposits in tributary valleys in sections 1 and 13, in the valley from the northwest at Cherokee as far up as the central part of section 21, and in the valley which enters from the northwest just south of Cherokee. The higher bench of the Little Sioux valley continues into both of these tributary valleys near Cherokee.

In Pilot township two small creek valleys from the east contain notable gravel and silt deposits. One of these is in sections 10 and 11 and the other in the north parts of sections 22 and 23. The higher terrace of the Little Sioux valley continues into the lower end of the valley in section 10 and is represented in this valley by gravel benches which extend almost to the township corner. Similar benches are present also in secondary branches from the southeast. In most of the exposures the material is clean fine gravel and quartz sand, as in the railway cut in the northeast quarter of section 11, and above a prominent spring zone on the south side of the valley near the west line of section 11. The valley contains also at some places deposits of silty sand and iron-stained silty material. In the lower part of the valley where the creek crosses the terrace of the Little Sioux, and at a number of places farther up the valley the gravel and silt deposit rests on Nebraskan till, but elsewhere and especially in the upper course of the valley it rests on Kansan till.

The higher bench of the Little Sioux valley also extends into the mouth of the tributary valley in the north part of section 22 and is marked by small benches on the valley sides eastward beyond the central line of section 23. At the mouth of the valley the terrace is eighty feet above the creek, but the gradient of the creek bed is so great that a mile east the benches are only fifteen feet above the stream. In this distance the terrace rises twenty-five feet but the creek rises ninety feet. Where the valley crosses the quarter-section line of section 23 the gravel rests on Kansan till, which in turn rests on Nebraskan till, but farther down the valley the Kansan till is absent and the valley-filling rests on the Nebraskan. The south slope of the valley in the northeast part of section 22 showed the following exposure:

		Feet.
5.	Alternating layers of gravel and sand with a few pebbles and bowlders	17
4.	Medium-grained sand, with coarser layers toward the top and grading into the silt horizon below	15
3.	Alternating thin layers of compact blue silt and sandy silt. Some of the silt layers are fossiliferous	17
2.	Coarse sand and fine gravel with a layer of bowlders at the base. Material much iron-stained and locally cemented. Copious springs issue from the base of this member	5
1.	Nebraskan till; a very tough greenish blue till with very few pebbles	9

The upper two members of this section appear to be the typical valley gravel. The silt member (No. 3) may be a slack water deposit put down in the tributary valley as the Little Sioux valley was being aggraded. Gravel is exposed in the slopes of this valley farther west, in the terrace of the Little Sioux, where a spring zone, twenty to twenty-five feet above the creek, probably marks the top of the Nebraskan till.

In the lower course of Parry creek, which drains the western part of Pilot township, there are a few benches high up on the slopes about seventy feet above the creek, and about thirty-five feet above the lower terrace in the Little Sioux valley. Benches are found at intervals up the valley. Rock creek, which joins the Little Sioux north of the center of Willow township, also has along its lower course benches which are continuous with high narrow benches along the Little Sioux valley to the north and south. These are present at intervals up the valley to the center of Rock township, and decrease in altitude until they are only fifteen feet above the creek.

Opposite Correctionville in northeastern Woodbury county, the high level bench of the Little Sioux valley, eighty feet above the river, continues into the lower end of Pierson creek valley. A gravel pit in this bench at the northwest corner of section 34, Union township, at the mouth of the valley, showed twenty-three feet of fine-grained gravel and sand. The Walsh Brothers' pit near the center of the southeast quarter of section 28, half a mile within the valley, showed twenty-five feet of gravel overlain by four feet of fine sand and above this about three feet of leached loess. An abandoned pit at the center of section 20 showed ten feet of gravel over blue Kansan till and overlain by three to five feet of sand and sandy clay. Benches of gravel continue up the west branch of the creek to Pierson and are present in the lower course of the north branch. The material exposed in these pits is almost entirely clean quartz sand and fine gravel, and is more worn than are the valley gravels farther north. Four analyses of pebbles from this valley show an average of 47 per cent igneous rocks, which is 11 per cent higher than the content of average valley gravels, and the sand averages about 95 per cent quartz grains. There are small snail shells in the gravel, and the pits in sections 34 and 28 have yielded some vertebrate remains (page 409).

The material overlying the gravel of the benches in the lower course of Pierson creek valley is not usually distinctive loess but leached loess overlies the gravel at the Walsh pit, and the sand and sandy clay of other exposures is undoubtedly the time equivalent of the loess. The stratigraphical position of the gravel below the loess is well shown on the north line of section 20 where a gully on the west slope of the north branch of the creek shows seven feet of loess, the upper three feet of which is leached, overlying twenty feet of gravel. The continuity of this gravel with that farther down the valley cannot be questioned, as this exposure is only half a mile from the pit exposure of section 20.

MAPLE RIVER DRAINAGE BASIN.

Maple river heads in northwestern Buena Vista county and flows southward through eastern Cherokee and Ida counties to Ida Grove. Here it changes direction to southwest and holds this course to its union with the Little Sioux southeast of Onawa. In eastern Cherokee county this river has a broad upland valley with a large flat, much of which is overflowed by the river at times of high water. In northeastern Ida county the valley is deeper where it enters the more rugged part of the Kansan drift-region and from here southward it is a broad, open valley more than 100 feet deep.

The basin of Maple river is separated from the Wisconsin drift-margin by the high north-south divide of western Buena Vista and Sac counties and by the Boyer river valley. No Wisconsin drainage could possibly have entered the valley.

The broad valley of Maple river through eastern Cherokee county is probably underlain with gravel material, but the river has only a shallow channel and gravel was seen at only a few places. In Galva township of northeastern Ida county, gravel was seen in benches at the northwest corner of section 10 and in sections 22, 27 and 34. The valley joining Maple river valley at Galva is bordered by gravel benches through the north part of section 23, and a pit just north of Galva shows ten feet of clean gravel and sand overlain by five feet of yellow loesslike clay which probably is leached loess.

At Ida Grove, Maple river is joined by Odebolt creek from the east. On the south side of the latter, in the west part of section 19, Blain township, there is an exposure of about fifteen feet of sand with a few pebbles, and there is an abandoned gravel pit just northeast of the railway station at Ida Grove.

BOYER RIVER DRAINAGE BASIN.

Boyer river heads southwest of Storm lake in southern Buena Vista county and flows east of south to southern Sac county. In this portion of its course it is four to six miles west of the Wisconsin drift-margin and received drainage from the Wisconsin ice by a break through the divide to the east just north of the Buena Vista-Sac county line and by the Wall lake outlet south of the town of Wall Lake. From southern Sac county, Boyer river flows southwest across Crawford and Harrison counties to Missouri river.

The headwaters of the Boyer river above Early occupy broad, upland valleys. Flat areas, that apparently are underlain with gravel, are found along the valleys of Eden township, but the streams have cut only shallow channels into them and exposures are few. In Boyer Valley and Clinton townships the valley is deeper. Gravel deposits were seen at a few places.

The Wall lake outlet connects the Boyer valley with the Wisconsin plain and with a great gravel deposit of Wisconsin age at the west end of Wall lake. The bottom of the outlet is a swampy flat, projections of which extend up small tributaries of the Boyer into northwest Levey township.

Southwest of the Wall lake outlet, across Crawford county, the Boyer valley has steep slopes and a flat bottom which is at flood plain level, and is in most places one-half to one mile wide. At a few places, especially at the mouths of tributary valleys, there are benches that look like remnants of a former valley filling.

Fossils From the Valley Gravels.

The valley gravels, especially in the southern part of the area, have yielded some fossil remains. These include both vertebrates and mollusks.

The two deep pits just northeast of LeMars (pages 394 to 395) have yielded a number of bones. They were brought up by the dredge scoop and are said to come from different depths. Among the material from these pits are elephant tusks and teeth, part of a pelvic girdle of an elephant, deer horns, horse teeth and a number of unidentified leg bones and vertebrae. Remains, chiefly deer horns, limb bones and vertebræ have been obtained also from the Erdman pit in the Floyd river valley in the northwest part of LeMars (page 393) and from the pit operated by C. H. Grimes in Deep creek valley one mile east of Oyens (page 394).

From the pit of the Cherokee Sand and Gravel Company north of Cherokee a tooth of *Elephas columbi*, an elephant tusk, and various small bone fragments have been taken.

Two specimens obtained from the pit of the Walsh Brothers in Pierson creek valley west of Correctionville were identified by Dr. O. P. Hay[55] as "a horn core and the base of a skull of a bison, both belonging to *Bison occidentalis*." The writer examined a large proboscidian tooth, a horn core, a horse tooth, and some pieces of unidentified bones which were taken from the gravel pit of Paul Fleming, at the mouth of Pierson creek valley. A few miles south of Correctionville, within the Little Sioux valley, is the Gilleas gravel pit, from which a "buffalo head", deer horns, a worn tooth of *Elephas primigenius* and various bone fragments have been taken.

Some proboscidian bones have been found in the gravel deposit of Rock river at Rock Rapids. This locality is well out in the Kansan drift area, but the valley may contain Wisconsin gravel.

The bones found in the gravels of northwestern Iowa are, so far as known, all isolated finds and many of the bones are worn. No complete skeletons have been found. The evidence is not such as to prove that the animals lived while the gravel was accumulating, although this was probably true.

Small snail shells were found in the gravel at several places in the southern part of the area, mostly in the tributary valleys of the Little Sioux at or near their union with the main valley. They were found in coarse sand and fine gravel as well as in silty sand and silt deposits.

In the creek valley in the northeast quarter of section 11, Pilot township, Cherokee county, gastropod shells were found in fresh coarse sand in a railway cut. In the next creek valley to the south in the northeast quarter of section 22 (page 407), small gastropod shells were found in a compact silt that forms part of the valley filling.

The gravel in the Paul Fleming pit at the mouth of Pierson creek, opposite Correctionville, contains many snail shells. At least five species were collected here, although most of the shells belonged to one species.

South of our area, in Crawford county, shell-bearing gravels were found in two tributary valleys of the Boyer. Along

[55]Iowa Geol. Survey, Vol. XXIII, p. 74.

Porter creek in Stockholm township, north of the village of Boyer, there is a gravel deposit which forms benches thirty to forty feet above the creek, and snail shells were found at several places in the fresh sand and fine gravel in these benches. At the lower end of the valley just southwest of Boyer, mussel shells (unios) were found in a brownish yellow to blue-gray silt zone. Farther south in the southwest part of section 6, Washington township, just above the mouth of the valley of Buck creek, which joins the Boyer near Arion, there is a bed of fresh, clean gravel which contains many gastropod shells. The zone is part of a thirty foot bank of sand and gravel which is overlain by fossiliferous loess.

All the gravels containing molluscan fossils and practically all those containing vertebrates are located in the southwest part of our area. None of the gravels of the northern part of our area are fossiliferous. The deposits along Mill creek and elsewhere were examined carefully for fossils, but none were found.

Origin and Age of the Valley Gravels.

The term valley gravels is intended particularly for those gravels which occupy valleys in the Kansan area that could not have been reached by outwash from the Wisconsin ice-sheet, and which are, therefore, not Wisconsin gravels. However, in the above discussion of the distribution of the gravels, all gravels occupying valleys have been treated, because in most cases it was not possible to differentiate those occupying valleys that did not receive Wisconsin drainage from those in valleys that did receive such drainage. In treating the origin we are concerned with only the true valley gravels.

The valley gravels rest on the Kansan till, except where the Kansan till had been entirely removed at the time of gravel deposition, as in the Little Sioux valley and the lower courses of some of its tributaries, in which case they rest on the Nebraskan till. The gravels are in valleys cut into or through the Kansan drift-sheet. They are therefore post-Kansan in age and must have been deposited only after sufficient time had elapsed to permit the previous development of the valleys to essentially their present depth and form. Furthermore it is believed (page 332) that the Kansan drift-plain remained for a great length of time in such a position that it was not being eroded, and that the gumbotil was developed on this plain. The region was then uplifted, and erosion had reduced the entire surface below the gumbotil plain before the deposition of the gravel took place. The gravel may, therefore, be much younger than the Kansan epoch.

The gravels are generally overlain by a pebbleless, loesslike clay which is continuous with a similar deposit over the upland. In the west and southwest parts of the area studied this deposit over the upland is the undoubted loess; and over the remainder of the Kansan drift of our region this deposit, although thinner and in most places leached for its entire thickness, is the time equivalent of the loess (page 343). The material overlying the valley gravel is, therefore, the time equivalent of the loess although it is not for the most part true loess in the lithological sense. The loesslike clay apparently was deposited soon after the gravels, for the top of the gravel deposit does not show the least indication of a weathered zone. In fact it appears that there was a transition from gravel deposition to deposition of loesslike clay, for there is at many places alternation of the two materials near the contact and a recurrence of sand and pebble bands in the lower twelve to eighteen inches of the loesslike clay. The lower part of this loesslike clay shows banding in some exposures and must be water laid. The upper part may be eolian, a method of origin which would accord better with its texture and its general lack of bedding.

The age of the gravel is, therefore, post-Kansan and pre-loess, which probably means pre-Iowan. It was deposited long after the Kansan epoch and probably just preceded the formation of the loess.

Most of these valley gravels of northwestern Iowa were interpreted as Wisconsin gravels by Professor Macbride. At first they were interpreted as being largely within the area of the Wisconsin drift, the boundary of that drift-sheet being placed far enough southwest to include O'Brien county; later, when the Wisconsin drift-boundary was shifted to the Ocheyedan-Little Sioux course (page 254) the gravels of the extra-morainic region were interpreted as being due to waters which broke over the great divide and flooded the country to the southwest. With the margin located across Sac, Buena Vista, Clay, Dickinson and Osceola counties as described in another part of this report (pages 255 to 287) it is possible to determine which streams could have received drainage from the Wisconsin ice. These are Big Sioux river; Rock river and its tributary, Little Rock river, with Otter creek; Little Sioux river and its tributary, Ocheyedan river, with the Little Ocheyedan; and Boyer river. The drainage courses of Floyd river, Mill creek, Waterman creek, Maple river and others which contain valley gravels could not have received Wisconsin drainage. Therefore, from the viewpoint of the possible distribution of Wisconsin outwash, the valley gravels could not all be of Wisconsin age.

In composition the gravel is like that of the clay-ball hills and the inclosed gravel-masses, and closely resembles the pebbles that may be picked from the Kansan till. Clay balls and shale pebbles are not common, as they are in the gravels of the gravel hills, indicating that these gravels were subjected to some transportation; and yet they were not transported far enough to wear out the limestones or to round the pebbles, most of which are subangular.

It is believed that the material that forms the valley gravels was derived from the Kansan till, from which it was released by erosion, and that it collected gradually in the valleys as the finer material was carried beyond the region. The conditions under which gravels would accumulate so widely in the valleys are not well understood. They may be climatic and associated with the decreased vegetation and increased erosion of an ice-epoch, during which, although the ice did not invade this region, its climatic effects were strongly felt. The gravels may represent the declining stage of a period of rapid erosion which had been caused by an uplift of the gumbotil plain.

It is thought that a method of uplift that affected first the northern region and then progressively regions farther south might afford an additional basis in explaining the phenomena. If the northern counties of the state were uplifted it would result in rapid erosion of that district. Later uplift farther south would result in rapid erosion in the newly uplifted part but would also have the effect of slackening erosion farther north and possibly might cause deposition. Uplift affecting regions progressively farther south might ultimately result in gravel deposition along most of the length of the southward flowing valleys. Gravel once deposited might be later shifted farther down the valley, which would result in the material being more and more worn.

It is believed that the method of origin outlined above is similar to the way in which the Aftonian gravels accumulated and that if the Kansan region of northwestern Iowa had been overridden by a later ice-sheet, deposits similar in position to the Aftonian gravels would have been formed.

CHAPTER VI

THE NEBRASKAN DRIFT.

The Nebraskan drift, under the name of pre-Kansan or sub-Aftonian, has been known in Iowa for many years.[56] The term Nebraskan was proposed by Professor Shimek in 1909.[57] In 1908, Professor Shimek discovered a mammalian fauna in the Aftonian gravels of western Iowa. This gave new impetus to the study of these gravels, and the Nebraskan drift below the gravels has since received more attention. The work of Professor Shimek in Harrison and Monona counties and later along the entire western border of Iowa has brought to light many exposures of Aftonian gravel and of the underlying Nebraskan drift between northern Missouri and the northwest corner of Iowa.[58]

GENERAL CHARACTERISTICS.

Within the region here considered the Nebraskan till is exposed chiefly within the valley of Little Sioux river, which in part of its course, chiefly in Cherokee county, has cut through the Kansan till into the Nebraskan. The bottom of the valley is

[56]For bibliography see Iowa Geol. Survey, Vol. XXII, pp. 661-663.
[57]Science, Vol. 31, p. 75, 1910.
[58]Shimek, B., Bull. Geol. Soc. America, Vol. 20, pp. 399-408; Vol. 21, pp. 119-140; Vol. 22, p. 730; Vol. 23, pp. 125-154. Iowa Geol. Survey, Vol. XX, pp. 304-366.

covered with alluvium and glacial gravels so that there are few exposures of the Nebraskan till and its extent at the surface is negligible, although the actual area where it directly underlies the alluvium and gravels may be considerable. The exposures of Nebraskan till are found in the valley bottom or in the lower parts of the bluffs, and at no place do they rise more than half way to the level of the upland. They are found also along the lower courses of some of the tributary streams, especially along Mill creek in northern Cherokee county.

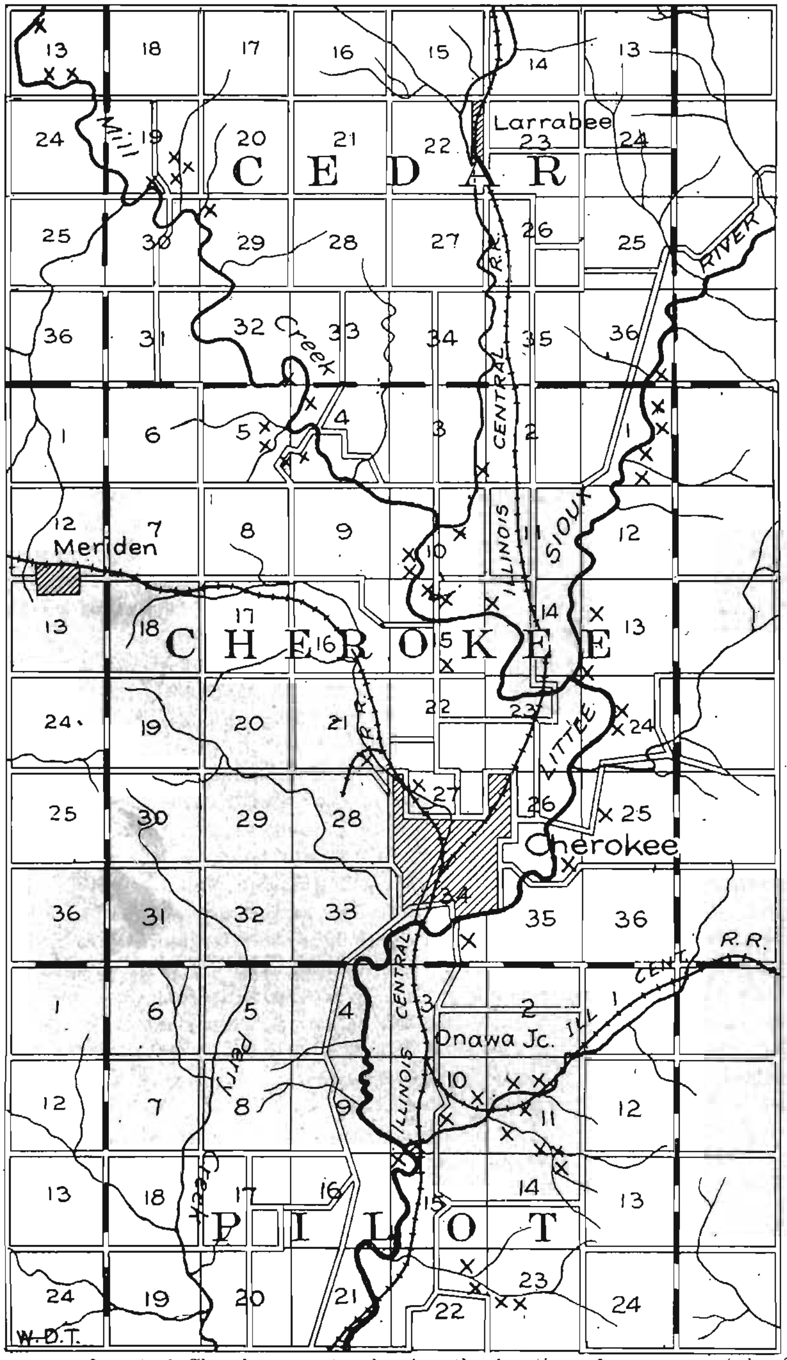
The Nebraskan till of Cherokee county is gray modified by various tints of chocolate, brown, purple and blue. The most common colors are chocolate gray and purplish gray, and generally the color is darker with greater depth beneath the face of the exposure. In its most weathered phase it has a yellowish cast. The till is almost free from pebbles or sand grains, and is so fine-grained that in most cases very little grit can be detected even when a small piece is tested between the teeth. The matrix of the till is commonly calcareous but at some places it is only slightly so or even is entirely free from calcareous material, although it is the fresh unaltered till. Calcareous concretions ranging in size from small grains to masses eight or ten inches across are found in the upper part of this till in some of the exposures. The till is compact and tough when fresh, but in most surface exposures it is loose, and can be dug easily with the hammer. It has a peculiar and characteristic method of fracture by which it breaks up into small angular fragments similar to those into which starch fractures on drying.

The Nebraskan is overlain by the valley gravels, by the Kansan till, or by silts and sandy silts, probably of Aftonian age. Aftonian gravel and sands, which are so general farther southwest, are not found here. The thickness of the Nebraskan till is not definitely known, for no exposure goes through it, and well records are usually too indefinite to distinguish between the Nebraskan and Kansan tills. In several exposures along the Little Sioux it rises fifty to seventy feet above the river, and the record of a well on the upland at the Cherokee State Hospital is interpreted as penetrating 170 feet of Nebraskan drift below seventy feet of Kansan. It is probable that the major portion of the 200 feet or more of Pleistocene material which covers parts of northwestern Iowa is Nebraskan drift.

In this region the Nebraskan till is easily distinguished from the Kansan. Its surface color is gray, while that of the Kansan is brownish yellow, and the fresh till has a darker color than has the Kansan under similar conditions. It is more compact and tougher than the Kansan, and is the abomination of those who dig wells and grade roads. It contains less grit and fewer pebbles and bowlders, and breaks up into much smaller fragments. The two tills are so distinct that in most places where the contact was exposed it was possible to locate the plane exactly, and in several places hand specimens could be taken that contained both tills. In some places the Kansan ice plowed up the Nebraskan till and left a transition zone at the contact.

South of our region in Carroll and Crawford counties and in places farther south the Nebraskan till is practically identical with the Kansan, since it oxidizes to the same yellow-brown color as the Kansan and contains much sand, pebble and bowldery material.[59] Also in this region to the south there is at the top of the Nebraskan a gumbotil which is similar to the gumbotil at the top of the Kansan till.[59a] This Nebraskan gumbotil is distinct from the Nebraskan till of that region, which is yellow when oxidized. The upper part of some of the Nebraskan exposures of our region may represent this gumbotil zone but its separation from the Nebraskan till below is more difficult because the latter is itself a gray, tough, almost pebbleless clay and does not oxidize to a yellow color. The limestone pebbles are gone but these are so rare in the fresh till that one must sometimes shave down half a bushel of the till before finding a pebble. The calcareous material must be leached from the matrix but as noted above the matrix of the fresh till is at some places without calcareous material. Furthermore, in the Nebraskan gumbotil there are calcareous concretions, which have been formed by the material carried down from the overlying Kansan till, and these may be small grains which are hardly recognizable until tested with acid. The work in northwestern Iowa was done before the Nebraskan gumbotil had been recognized in southern Iowa, and later work may differentiate it in this region.

[59]Kay, G. F., Iowa Geol. Surv., Vol. XXVI, p. 231.
[59a]Kay, G. F., Science, Vol. 44, p. 637; Iowa Geol. Surv., Vol. XXVI, pp. 217 and 231.



A map of central Cherokee county showing the location of exposures (x) of Nebraskan till.

DISTRIBUTION AND DESCRIPTION OF OUTCROPS.

There are many exposures of Nebraskan till in central Cherokee county and a number of these will be described here. The locations of the more important of these exposures are shown on Plate XXV.

In the northwest corner of section 15, Pilot township, at a point where the river changes direction from west to south, the west bank of the channel exposes a hard blue-black clay that apparently is Nebraskan till. It has a starchlike fracture, rises three to four feet above low-water level, has a thin reddish brown band at the top and is overlain by a layer of ferruginous material with many cobbles and bowlders. Above a rise of a few feet in which the material is not exposed, the bench gravel is exposed and rises thirty feet to the terrace level.

The creek valley in sections 22 and 23, Pilot township (pages 406 to 408) has some good Nebraskan till exposures along its lower course (Plate XXV). Just east of the quarter-section line of section 23 a tributary ravine from the south shows twenty feet of Nebraskan till overlain directly by Kansan till. The Nebraskan till here is a gray compact clay which breaks into small angular fragments. It contains very little grit, but few pebbles, and many calcareous concretions. Other exposures of the Nebraskan-Kansan contact are found along the south slope of the creek valley for twenty or thirty rods west of the quarter-section line and none of them show gravel between the tills. In one exposure in a ravine from the south about twenty rods west of the quarter-section line, there is between the tills a purplish gray siltlike clay with bands of dark alluvium, and this is probably reworked Nebraskan material of Aftonian age.

Farther down the valley there are several exposures of Nebraskan till overlain by the valley-filling material without the intervention of Kansan till. Near the center of the northeast quarter of section 22 the Nebraskan till rises about nine feet above the creek in the base of a large slide (No. 1 of section on page 407.) The till here is very tough greenish blue clay with very few pebbles. It is overlain by five feet of much rusted gravel with a layer of bowlders at the contact. The gravel has an indurated ferruginous zone at the top, and irregular cemented masses lie on the slope. Strong springs issue from the base of the gravel zone at the top of the Nebraskan, and springs at similar altitude at other places along the valley probably come from the same horizon. Above this horizon rises fifty feet of bedded valley-filling material that is dominantly silt and fine sand in the lower part and dominantly gravel toward the top. The valley-filling material here rests on the Nebraskan till but it occupies a valley cut into and through the Kansan till and rises to a bench within a post-Kansan valley. It is, therefore, of post-Kansan age and was deposited in a valley which had been cut through the Kansan till and which had its bed, as at present, in the Nebraskan till.

About 100 yards northwest of the large slide exposure the Nebraskan till rises ten feet above the creek. It is here a dark greenish blue clay, which in the upper part is weathered and contains much concretionary calcareous material.

Farther north in Pilot township there are a number of small exposures of Nebraskan till in the lower part of the slopes of the creek valley in sections 10 and 11 (Plate XXV). The Nebraskan till here is blue-gray clay with very few pebbles or grains of sand. It is sticky and gummy when wet and dries with a very hard crust. On slopes that have been exposed for years the till is loose, and breaks out with the starchlike fracture. It contains calcareous material along joints and as concretions.

Within the area of the Little Sioux bench in the central part of section 10, the Nebraskan till is exposed in the road-cuts on both slopes of the creek valley and in a railway cut just south of the creek. In all these exposures the Nebraskan is overlain by the gravel horizon of the terrace. In the road-cut in the north slope of the valley the till is exposed through a vertical range of thirty to forty feet and rises to an altitude of 1240 feet above sea level, or about eighty feet above the Little Sioux. In a railway cut on the east line of section 10 the blue-gray Nebraskan till is exposed, while higher up the valley slope the Kansan till outcrops. Other exposures were seen in the ravine from the north in the northwest quarter of section 11; in the slope on the south of the railway, just west of the quarter-section line of section 11; at the southwest end of a railway cut in the northeast quarter of section 11; and in the creek bank south of the east end of this railway cut. Nebraskan till exposures appear also along the tributary valley from the southeast in the southeast quarter of section 11, and the northeast quarter of section 14.

The Nebraskan till is exposed in the lower part of the terrace front of the Little Sioux valley, along the road leading south from Cherokee. The road-bed here has been sunk a few feet below the natural surface and the till exposed at the road-side is so hard that at a few inches beneath the surface little impression can be made on it with a hand pick. Those who helped cut the road tell in strong terms of the toughness of the clay. A little farther up the slope a ravine bed east of the road shows a more weathered phase which is less hard, is plastic and gummy where wet, and is streaked with calcareous material. The upper contact of the Nebraskan till was not seen here but the till apparently is overlain directly by the gravel layer which forms the upper fifteen to twenty feet of the slope which rises to the level of the terrace.

In two wells about fifty yards west of these roadside exposures and near the top of the slope, a very hard, blue-black clay was struck just below the gravel and one of these wells penetrated this horizon about ninety-five feet without striking any water-bearing material. This depth would place the bottom of the well at an altitude of about 1120 feet above sea level, or forty-five feet below Little Sioux river. About 200 yards west of the road, at the east end of the old Illinois Central Railway gravel pit, the Kansan till underlies the gravel at about the same altitude as the Nebraskan till exposures along the road.

The town of Cherokee stands on a bench about thirty-five feet above the river. Gravel underlies the bench directly but in 1913 several sewer ditches in the northeast part of town exposed Nebraskan till at a depth of three to five feet. A layer of bowlders, some of them two to three feet in diameter, rests on the till.

One mile northwest of Cherokee, in the northwest corner of section 27 (Plate XXV), a railway cut exposed the weathered, loose phase of the Nebraskan till, which was overlain by the valley gravels. A few rods away another cut exposed fifteen feet of Kansan till, also overlain by the valley gravels. These exposures and those just south of Cherokee noted above, show how the gravels may rest on the Nebraskan and the Kansan tills at points close together. Where the railway spur to the State Hospital grounds crosses the creek in the southeast quarter of section 21, the excavations for the bridge piers exposed in 1916 about ten feet of chocolate-gray Nebraskan till, which contained a few pebbles, and also had many irregular calcareous concretions in its upper part.

Nebraskan till is exposed in the lower part of the east slope of the Little Sioux valley along the wagon road leading east from Cherokee (Plate XXV). The exposure extends along the road for more than 100 feet and for most of this distance the cut is ten to twelve feet deep. It covers a vertical distance of thirty-five feet and rises to an elevation of 1250 feet above sea level, or approximately eighty feet above the river. The lower part of the exposure shows blue-gray compact gummy clay that is slightly calcareous and contains a few limestone pebbles. It has the typical starchlike fracture of the Nebraskan and at a depth of six to nine inches below the face of the exposure the clay is very compact and hard. The upper part of the exposure, about fifteen feet, is not the typical Nebraskan till, although it is very similar. This part is more plastic, looks like a massive silt deposit and breaks up into small fragments similar to the starch fracture. This zone contains calcareous matter as powdery material along the joints, and in the form of concretions, whose diameters range from the size of sand grains to two inches, but no limestone pebbles were found and the matrix is thought to be leached. However, it is difficult to determine whether the effervescence produced is by a small concretion, by a small grain of limestone, or by a calcareous matrix of clay. It is believed that this zone is the Nebraskan gumbotil, that it was thoroughly leached before the Kansan epoch and that the calcareous material is all in the form of concretions and has been carried down from the Kansan till above. The upper contact of the Nebraskan till was not exposed, but Kansan till is exposed twenty-five yards farther east and twenty-five feet higher and this continues to the top of the slope.

Fifty yards east of the turn in the road at the base of the bluff in the west part of section 25, Cherokee township, a small gully exposes yellow-brown Kansan till over a black humus-bearing tough clay, which apparently is the top of the Nebraskan. Farther north along the bluff at the same altitude there are several places where water seeps out, and just down the slope is a black gumbo material that is probably derived from the Nebraskan till.

Along the east bank of the Little Sioux in the west part of section 24 and the southwest quarter of section 13, are a number of exposures of Nebraskan till (Plate XXV). The most southerly of these exposures are in the north part of the southwest quarter of section 24, where the river flows close to the base of the bluff. At several places the Nebraskan till rises ten to twelve feet above the river. At short intervals farther north there are Nebraskan exposures, some of which rise twenty feet above the water. The slopes are badly slumped and Kansan till is in many places mixed with, or slumped down over the Nebraskan till.

In the northwest quarter of section 24, where the river swings farthest to the east, there is a big slide exposure. It is largely slumped over but enough can be seen to make out the general succession. Nebraskan till rises fifty-five feet above the river and is overlain by Kansan till. The exposure is about twenty-five yards across at the Nebraskan-Kansan contact, and at several places this contact was exposed by digging. At most places the tills are in contact, but at one place about four inches of a yellowish silty sand separates them and near the south end of the exposure there is at the contaet a mass of yellow sand and gravel with bowlders, that appears to rest partly in a depression in the Nebraskan till.

About eighty rods north of the southwest corner of section 13, the Nebraskan till outcrops at river level and rises in the bank for about ten feet. Part of the exposure is slumped over with Kansan till from above and a few yards along the bank Kansan till, apparently in place but probably a large slump, comes down to water level. The slope above is slumped and grassed over nearly to the top of the bluff. Other exposures of Nebraskan were seen in a ravine in the southwest part of the northwest quarter of section 13.

Section 1, east of the river, contains a number of Nebraskan drift exposures in the lower part of the bluff of the Little Sioux valley and in tributary valleys (Plate XXV). A Nebraskan till exposure in the slope of the Little Sioux valley about sixty rods south of the center of the section is almost continuous for thirty feet, and rises to fifty feet above the river, and in a ravine valley to the east, exposures appear up to sixty feet above the river. In the south half of the northeast quarter of section 1 the Nebraskan till is exposed in a gully from thirty feet to forty-five feet above the river.

One hundred yards west of the east line of the northeast quarter of section 1, the south slope of a ravine shows the Nebraskan till rising eighteen feet above the ravine bed. This is overlain by two and one-half feet of grayish black material in which were found a few fragments of snail shells. This is probably an Aftonian silt horizon but it is very compact and without laminæ. It is overlain directly by fifteen feet of Kansan till and then the gravel zone rises to the bench level. In the gutter along the road which rises eastward on the north line of section 1, small exposures show the Nebraskan till between thirty feet and forty feet above the river, the black silts with shell fragments at fifty feet and Kansan till between fifty-five feet and seventy-five feet above the river.

The east bluff of the Little Sioux valley about sixty rods north of the south line of section 36, Cedar township, shows a large exposure in which the Nebraskan till extends from the river level fifty-five feet above the water and is overlain directly by the Kansan till. The river is undercutting the bluff at this point and the Nebraskan till is fresh. Near the river level it has a reddish chocolate or dark reddish brown color, but higher up it takes the usual gray color. At the contact, the two tills are much alike and seem to grade into each other, but a few feet on either side of the contact they are distinct and the similarity at the contact apparently is due to a mixing of the two tills. The Nebraskan till breaks into small blocklike pieces and has very few sand grains or pebbles; the Kansan breaks into elongate flakes, is much more gritty, and shows more ferruginous staining along the joints. A few feet above the river at the south end of the exposure there was a lens of greenish gray sand a foot thick and two feet long, and about ten feet above the river was a seam of sandy silt two to three inches thick and about eight feet long. Such inclusions of sandy material in the Nebraskan till are exceptional.

More than sixty exposures of Nebraskan till were seen along Mill creek valley and its immediate tributaries in northern Cherokee county. The locations of many of these are shown in Plate XXV. In the bluff of Mill creek in the southwest quarter of the northwest quarter of section 14, Cherokee township, the first gully east of a large ravine from the north shows Nebraskan till forty-five feet above the creek, and another gully farther east shows Nebraskan till fifteen feet above the creek. The Nebraskan till of these exposures weathers yellow as if it were mixed with Kansan till.

Other exposures of Nebraskan till were seen on the east slope of the large ravine from the north near the west line of section 14; in a ravine near the south line of the southeast quarter of section 15, where it is overlain directly by recent alluvium; in a road-cut north of the house on the H. L. Phipps farm in the north part of section 15; and in the east bank of Mill creek near the quarter-corner on the north of section 15, where it rises forty feet above the creek.

In the west bank of Mill creek sixty to eighty rods north of the south line of section 10, the Nebraskan till rises fifty feet above the creek. At the water level the till has a blue-black color beneath the surface and at a depth of a foot it is exceedingly tough and sticky. Higher up the slope the color is gray at the surface and chocolate-gray beneath. Where it is most weathered it has a yellowish cast. The starchlike fracture is well developed.

In the southeast corner of section 3, Cherokee township, in the valley of a tributary of Mill creek, a steep northward-facing slope shows Nebraskan till rising thirty feet above the creek. The color of the till is gray or yellowish gray at the surface, and chocolate-gray beneath. It has the typical starchlike fracture of the Nebraskan but in this exposure is not very hard. It contains a few pebbles and the matrix is commonly only slightly calcareous. The upper fifteen feet of this horizon contains calcareous concretions as large as two inches in diameter. Fragments of small snail shells were found at several places in this upper part and it is possible that the upper part of the stratum consists of reworked Nebraskan till which forms a compact Aftonian silt. This member is overlain by Kansan till which is only three to four feet thick at the west end of the exposure, thins to less than one foot at the center and apparently is six feet thick at the east end. The whole exposure at this horizon is greatly slumped. Near its base the Kansan till here contains much of the material from below; and yet they are readily distinguishable, and the contact is so definite that hand specimens may be removed containing the two materials. At a short distance above the contact the till is as a rule unquestioned Kansan.

Overlying the Kansan till is a zone, one to three feet thick, consisting of dark greenish or grayish sandy material below, and a black soil-like material above. Both the sands and the soil zone contain shell fragments among which a Unio, a small pelecypod and small snails were recognized. The Kansan till is locally entirely absent and in such places this zone rests on the Nebraskan. Higher up the exposure is very badly slumped. It seems to consist of a twelve to fifteen foot zone of bluish and yellowish sandy silts and silty sands, overlain by twenty to twenty-five feet of the usual valley gravels.

Nebraskan till is exposed along the road that leads down to Mill creek in the southwest corner of section 5, Cherokee township, where it is overlain sharply by the Kansan till (pages 424 to 430), and in the lower course of the ravine that extends northeast across the southeast quarter of section 5, where it rises fifteen feet in the bank (Plate XXV). In the latter exposure it is the weathered phase and has a light grayish blue color at the surface but is dark blue-black below. At the surface it is cracked and loose where it is dry and it looks like a slaked shale exposure, but at a short distance below the surface it is quite hard.

Near the center of the northwest quarter of section 4 Mill creek is undercutting its east bluff and has uncovered a large face of Nebraskan till which extends along the slope for several rods and rises in the bluff to fifty feet above the creek. This is overlain by forty feet of Kansan till. The Nebraskan till of this exposure is a loose chocolate-gray clay. It is unleached, with a few limestone pebbles even at the top of the zone, but at a number of places the matrix is practically free from calcareous material. The till contains many calcareous concretions, some of which are four to six inches in diameter and a few slablike masses were seen which were as much as twelve inches across. Several of these concretions were found to have pebbles at their centers. The concretions appear to be in place even down to twenty to thirty feet below the top of the horizon. A mass of iron-stained, partly cemented gravel four to six feet across was seen enclosed in the Nebraskan till of this exposure. Other exposures of the till appear in the south bank of a creek valley from the west in the east part of section 5, where thirty feet of till is exposed beneath the gravels of the bench area; and in the northeast corner of section 5, where it rises thirty-five feet above the creek and is overlain by a thick layer of gravel.

Farther north up Mill creek valley, in Cedar township, Nebraskan till is exposed in the northwest corner of section 29, where in the east slope of a side ravine from the northeast it is overlain directly by the valley gravels; and near the mouth of the narrow ravine crossed by the road in the south part of section 19, where fifteen feet of Nebraskan till is overlain, up the ravine, by about forty-five feet of Kansan till.

Along the ravine in the north half of the southeast quarter of section 19, Cedar township, there are several exposures of Nebraskan till which rise ten to twelve feet above the stream and are overlain directly by Kansan till. Farther up the ravine, north of the quarter-section line, a grayish black horizon containing a large amount of carbonaceous matter and showing plant impressions and a few decayed stems rises in one exposure three feet, in another five feet, above the ravine bed. It is overlain directly by the Kansan till and its base is not exposed. Where the Kansan and the Nebraskan tills are both present this zone was not observed, but it is probably an old soil and surface accumulation of Aftonian age.

In the north bank of Mill creek in the southwest quarter of the southeast quarter of section 13, Liberty township, Nebraskan till outcrops along the bank for about sixty rods and rises ten to fifteen feet above the water. At several places the Kansan till overlies the Nebraskan with a sharp contact, but in other places a thin gravel layer or pebble zone separates the two tills.

The most northerly exposure of Nebraskan till known along Mill creek is about forty rods south of the north line of section 13, Liberty township. In one part, the Nebraskan till rises fifteen feet above the creek but the contact is uneven and a short distance to the north the Kansan till comes down to water level. The contact is covered by slumped material but at one place where it was exposed by digging the Kansan till rests directly on the Nebraskan.

Aside from the Nebraskan till exposures of central Cherokee county a few others were observed. To the south there is questionable Nebraskan till in the bank of Little Sioux river just east of a gravel pit in the north part of Anthon, in eastcentral Woodbury county. The till rises ten to twelve feet above the river without exposing its upper contact, but a few rods away and at a slightly higher altitude Kansan till appears in the bottom of a pit in the valley gravels. The Nebraskan till of this exposure may be only a great mass included in the Kansan.

North of central Cherokee county along the Little Sioux valley Nebraskan till is exposed in the south bluff in the northwest quarter of section 25, Waterman township, O'Brien county, and in the river bank at Peterson in southwestern Clay county. In the first exposure the Nebraskan is a chocolate-brown clay with very few pebbles and almost no grit and has a well developed starch fracture. It rises eighteen feet above the river level and is overlain directly by the Kansan till. Just east of the east bridge at Peterson the chocolate-brown Nebraskan till rises in the north bank three to four feet above the river, and it appears at river level in the south bank near the east line of section 32. The exposure just east of Peterson is the last Nebraskan outcrop seen in passing up the Little Sioux valley.

A GROOVED AND STRIATED NEBRASKAN-KANSAN CONTACT PLANE.

In the southwest corner of section 5, Cherokee township, a road from the upland descends a small ravine to Mill creek (Plate XXV), and there was shown at the roadside in 1911 and 1913 a good exposure at the Nebraskan-Kansan contact. The contact is essentially horizontal for the length of the exposure, twelve to fifteen yards, and passes in one direction beneath the level of the road, while in the other direction it rises above the road-cut, and is concealed in the grass-covered slope. The contact plane was followed into the bank (east) a few feet, and in that direction also it is approximately horizontal. The Nebraskan till below is tough purplish gray clay, with very few sand grains or pebbles, but with some calcareous nodules. The Kansan till above is bluish black clay when fresh, and weathers to the usual brownish yellow color. It contains considerable grit and many pebbles. The contact plane is very definite, without a transition zone, so that it is possible to remove hand specimens that contain the two very distinct tills. The upper till can be removed so as to leave the surface of the lower till exposed, or a block containing the two tills can be removed and then separated along the contact.

Both surfaces of the contact, the Nebraskan below and the Kansan above, are smoothed to an even plane. These surfaces are marked by parallel grooves and ridges, the larger of which measure a quarter to a half an inch across, and a sixteenth to an eighth of an inch in depth or height. From these they grade down to the very finest of line striations, which cover the entire surface, even the slopes of the larger ridges and grooves. A view of these contact surfaces is shown in figure 60.

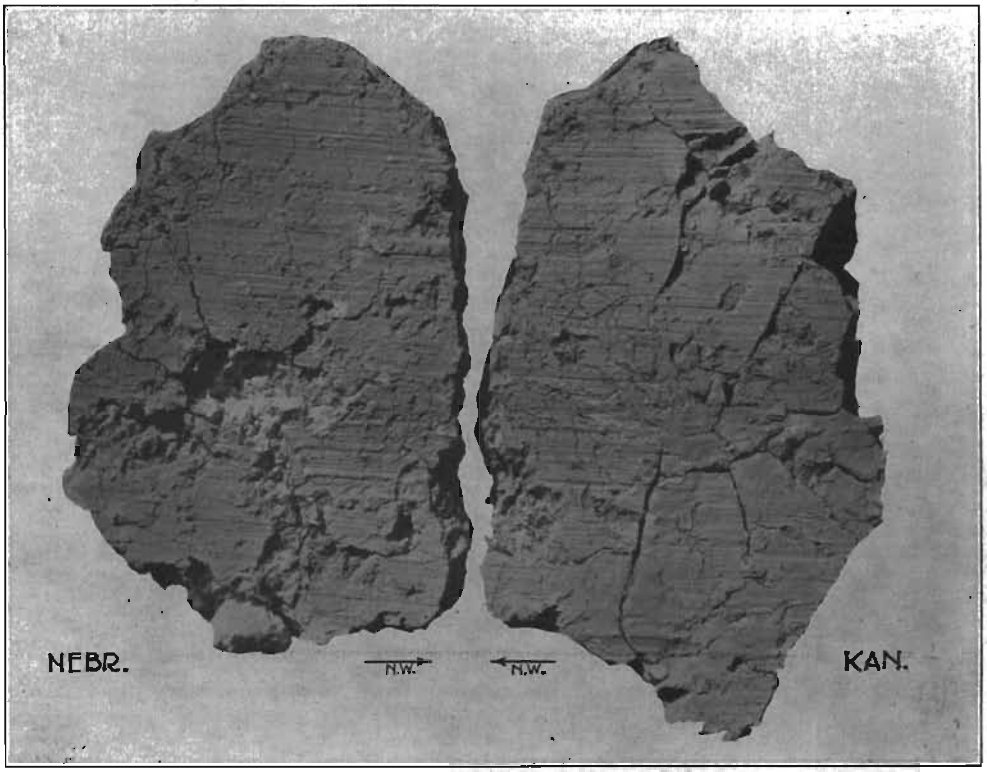


FIG. 60. A grooved and striated contact plane between the Nebraskan and the Kansan tills. A mass of clay containing the Nebraskan-Kansan contact was removed from the bank and later was separated along the contact plane. The Nebraskan is on the left and the Kansan on the right. A close study of the figure will show that one surface is the exact counterpart of the other. For description of features shown see text.

The under surface of the Kansan till above the contact plane is veneered with a thin layer of Nebraskan till so that both sides of the contact really show Nebraskan material. This veneer commonly has a thickness of about an eighth of an inch, but in some places it is lacking altogether and in some places it evens up the lower surface of the Kansan till by being several inches thick. The Nebraskan till contains very few pebbles but small calcareous concretions are rather abundant. These appear on the face both above and below the contact plane, but are much more abundant on the lower side. In either position they may be smoothed and striated. In some cases, a single striation can be traced from the clay across a pebble face and onto the clay again. The direction of the grooves and striæ of this exposure is N. 60° W.—S. 60° E.

The surface on one side of the plane is the exact counterpart of that on the other, the elevations or ridges of the one fitting into the depressions or grooves of the other. Where a pebble projects above the general surface of the Nebraskan, its northwest slope is buried in clay which forms the beginning of a ridge of clay that continues to the northwest (figure 60). The southeast slope has no clay on it and is more worn and striated than the northwest slope. Around the lateral slopes of the pebble, as seen from the southeast, little grooves are in some cases dug out, and striae approaching the lateral parts of the pebble from the southeast swing to the right or left of these grooves, pass around the lateral slopes, and then extend directly on to the northwest, not swinging back behind the pebble. Where a pebble projects from the lower side of the contact plane there is an exact impression of the projecting part of the pebble directly opposite in the surface above the plane, and this impression is the beginning of a groove which continues to the northwest. The groove, terminating to the southeast with an impression of the pebble, fits down over the ridge which terminates with the pebble itself (figure 60). If the profile of the projecting pebble normal to the direction of grooving is uneven, the ridge to the northwest of the pebble and the groove which fits down over this ridge will show a corresponding uneven cross-profile.

A smaller number of pebbles and concretions project from the plane above the contact. These have the northwest slope more worn and striated, while the southeast slope is buried in clay, which forms the beginning of a ridge which continues to the southeast. A pebble of this upper surface projects downward into an impression in the lower surface and this depression is the beginning of a groove that continues to the southeast, and contains the ridge projecting from the upper surface.

The upper side of the contact plane is not the mold of the lower side. This is shown by the following points. (1) The surface facing downward on the contact plane is striated, the same as the surface facing upward. Although grooves and ridges could be molded, it is probably not possible to mold striæ or striæ ridges which are too small to allow clay to fit down over or into them. (2) The pebbles projecting downward from the upper side of the contact plane are striated parallel with the grooves, and to accomplish this they must have been in their present position in contact with the lower till surface over which they were shoved. (3) For each pebble projecting from one surface there is a groove on the other surface, and the shape of this groove shows that it is the path along which the pebble passed. (4) The contact plane, which represents the plane of movement, is below a thin layer of Nebraskan till which veneers the base of the Kansan. This veneer was adhering to the Kansan till when the grooves were made. These lines of evidence prove that the upper surface of clay, the Kansan, was in contact with the lower when the grooves and striæ were made, and that each surface striated the other.

The relation of the features is evident. The smooth contact plane was made by the movement of the Kansan till above the plane, over the surface of the Nebraskan till below the plane. The grooves were made by the projecting pebbles and mark the paths along which the pebbles have passed. The pebbles projecting into the impressions, occupy the very positions in which they were left when movement along the contact plane stopped. The minor grooves and striations also were made by small pebbles or sand grains projecting from the opposite side, and many examples were observed showing striæ terminating directly opposite the sand grains which made them. The ridges are on the lee side of the pebbles, and were protected by the pebbles.

We have, therefore, these facts: A smoothed, grooved and striated contact plane between the Nebraskan and Kansan tills, made by the movement of the Kansan till on the Nebraskan till.

As to the cause of this movement, two hypotheses will be considered. (1) Hill-side slumping, or sliding of the upper till on the lower. (2) The movement of the Kansan ice-sheet as it pushed over the Nebraskan till.

The movement of one rock mass on another when under great pressure produces smoothing of the rock surfaces (slickensides), and striated surfaces are common in mines and have been observed in tough clay that has been blasted. The slope upon which the contact here considered appears, is steep but the contact plane in so far as it could be exposed is essentially horizontal, and the weight was only that furnished by fifteen to twenty feet of overlying till.

An ice-sheet shod with stones will groove and striate a bedrock surface, but the question here is, can it groove and striate a surface of till? If the feature was made by an ice-sheet, it was the base of a drift-shod ice-sheet that did the work, rather than the ice itself, for, as shown above, the Kansan till was resting on the Nebraskan till when the phenomenon was developed.

The slope upon which the exposure appears faces the northwest. If slumping produced this contact the motion must have been from southeast to northwest. On the other hand if glaciation produced the feature the movement probably was in the opposite direction, from northwest to southeast.

Where a pebble projects from the lower surface, the groove on the upper surface extends to the northwest. This means that the portion of the upper surface to the northwest of the projecting pebble has passed over the pebble by a movement from southeast to northwest. In the case of a pebble projecting from the upper or Kansan side of the contact, there is a groove in the lower surface to the southeast, that is in the portion of the lower surface over which the pebble has come. This again indicates a motion from southeast to northwest. Also the pebbles projecting from the lower surface are more worn and striated on the southeast side, while those projecting from the upper surface are more worn on the northwest side. This also shows a motion from southeast to northwest.

The evidence seems very conclusive that the part above the contact plane moved from southeast to northwest (S. 60 E.—

N. 60 W.). This is the direction in which slumping would take place, and a direction in which the Kansan ice-sheet certainly did not move. We therefore interpret this grooved and striated contact plane as the work of hillside creep or sliding of the Kansan till upon the Nebraskan.

This phenomenon was first seen in September, 1911. A hasty study in the field and the study of a few specimens brought in led the writer to think that the direction of movement was from northwest to southeast, and the feature was interpreted as the work of glaciation. A short paper on the subject was read before the Washington meeting of the Geological Society of America in December, 1911. The paper was not printed, but abstracts appeared in Science (Vol. 35, p. 316) and in the Bulletin of the Geological Society of America (Vol. 23, p. 735). A later study in the field showed that a mistake had been made in labeling the orientation of the earlier specimens taken, and that the features showed instead a movement from southeast to northwest. This opportunity is taken to correct the error recorded in the abstracts noted above.

At least two exposures in the ravine in the east half of section 19, Cedar township (page 423), show the smoothed, striated contact plane at the Nebraskan-Kansan contact. The exposures are greatly slumped and masses containing the contact plane have been moved down the slopes at several places. The features which indicate the direction of motion are poorly developed and it was not possible to prove the direction of motion. In the second exposure south of the quarter-section line, in the east bank, the direction of striation is N. 40° W.—S. 40° E. The bank is normal to this direction and faces the northwest. The evidence is slightly in favor of movement in a northwest direction. In an exposure in the west bank, sixty to eighty rods south of the quarter-section line, the direction of striation is N. 70° E.—S. 70° W. The bank here is normal to this direction, and slumping would require movement in the direction N. 70° E., which is apparently the direction indicated. These two exposures are only forty to sixty rods apart, but the difference between the direction of grooving is 110°. If glaciation had produced these contact planes the direction of grooving would be approximately the same. The direction of grooving is in both cases normal to the face of the bank and the conclusion is that slumping or creep produced the contact planes.

CHAPTER VII

THE GEOLOGIC HISTORY OF NORTHWESTERN IOWA.

The Pleistocene deposits of northwestern Iowa have now been treated in considerable detail. Practically nothing has been said, however, concerning the bedrock of the region; first, because this is primarily a report on the Pleistocene deposits; and second, because there was very little opportunity for collecting new data on the bedrock formations, which, over most of the areas, are deeply buried by the Pleistocene deposits. In this chapter there will be brought together, chiefly from the literature, some data concerning the bedrock of northwestern Iowa, and then the geologic history of the region will be traced in so far as this is recorded by the bedrock and the glacial deposits.

The Bedrock of Northwestern Iowa.

Within our region the bedrock outcrops chiefly in the slopes of the Big Sioux and the Missouri valleys along the west boundary of the state. Along the west line of Plymouth and northern Woodbury counties, there are many small outcrops, along the west line of southern Sioux county there are a few, and in Lyon county there are two or three outcrops in the very northwest corner of the state. Away from these valleys only two small exposures of bedrock have been reported within the region. The areal extent of all these outcrops is negligible for they are small and most of them are in steep valley-slopes. Ten of the sixteen counties comprising the region here considered are without a single known outcrop of the bedrock.

Two widely separated divisions of the geologic column are represented by the bedrock of the Big Sioux valley, for the few outcrops in northwestern Lyon county are of Proterozoic rocks while those of the counties to the south are of Cretaceous rocks.

The table given herewith shows the principal divisions of the geologic time scale, those divisions which are represented by deposits in northwestern Iowa being printed in italics.

ERA	PERIOD	EPOCH
Cenozoic	*Pleistocene* Tertiary	*Wisconsin* Peorian Iowan Sangamon Illinoian *Yarmouth* *Kansan* *Aftonian* *Nebraskan*
Mesozoic	*Cretaceous* *(Upper Cretaceous)* Comanchean (Lower Cretaceous) Jurassic Triassic	Laramie Montana *Colorado*: Niobrara; *Benton* (Carlile, *Greenhorn*, *Graneros*)
Paleozoic	Permian Pennsylvanian (Upper Carboniferous) Mississippian (Lower Carboniferous) Devonian Silurian Ordovician Cambrian	
Proterozoic	Keweenawan *Huronian*	*Sioux Quartzite*
Archeozoic		

THE PROTEROZOIC—SIOUX QUARTZITE.

In the northwest corner of Lyon county there are two exposures of the Sioux quartzite. One of these is in the extreme northwest section of the state within the valley of Big Sioux river, where the rock stands as a ridge twenty feet high and about a quarter of a mile long. The other exposure is two miles east in a small valley in the north part of section 7, Sioux township. These two exposures in Iowa lie on the south border of a large area of quartzite which extends north to Flandreau, South Dakota, a distance of forty-five miles, and has its eastern limit at Redstone Ridge, Cottonwood county, Minnesota, and its western limit at Mitchell, South Dakota. The rock is well exposed at Rowena, South Dakota, just north of the exposures on the Iowa side, in the quarries at East Sioux Falls, in and around Sioux Falls, and at many other places in southwestern Minnesota and eastern South Dakota.

FIG. 61. An exposure of Sioux quartzite at Jasper pool, near the northwest corner of Lyon county. The view shows the stratification of the quartzite, which here dips northward.

The Sioux quartzite is a very hard pink to red vitreous rock. It consists of rounded quartz sand grains, so firmly cemented with silica that the whole resembles a mass of quartz. It is stratified in layers from a few inches to a few feet thick (figure 61), and at some places shows lamination and cross-bedding and ripple-marked bedding planes.

The area within which the Sioux quartzite directly underlies the drift in northwestern Iowa can not be very definitely outlined. Thirty miles east of the exposures in the northwest corner of Iowa, at Ellsworth, Minnesota, 100 feet of Cretaceous rocks intervene between the drift and the quartzite, and twenty-five miles south, at Hudson, South Dakota, there is at least 150 feet of Cretaceous rocks beneath the drift. The actual extent within which the quartzite directly underlies the drift is probably well within these limiting points, and probably amounts to no more than a township in northwestern Lyon county.

The Sioux quartzite and other ancient rocks of Proterozoic and Archean age, form a basal foundation for northwestern Iowa. The upper surface of these old rocks dips southward from its outcrop at an altitude of more than 1400 feet above sea level in the northwest corner of Lyon county, and as shown by well borings, is 878 feet above sea level at Hull in Sioux county, 215 feet above sea level at LeMars, and 135 feet below sea level at Sioux City (figure 62).

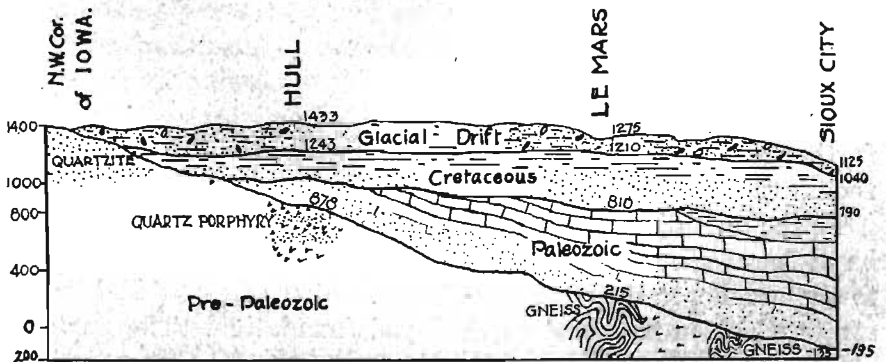


FIG. 62. A geologic section from the northwest corner of the state southward to Sioux City.

THE CRETACEOUS.

Northwestern Iowa lies just within the eastern margin of the great area of Cretaceous rocks of the Great Plains, and the chief bedrock formations belong to the Cretaceous system. The divisions represented are the Dakota formation and the three members of the Benton formation (see table, page 431).

Outcrops appear at intervals in the slopes of the Big Sioux valley south from the mouth of Rock river and in the bluffs of the Missouri valley south to Sargent Bluff, six miles south of Sioux City. Away from the large valleys on the west, as noted above, only two bedrock outcrops have been reported within the region, and these are both of Cretaceous age. One of these, reported by Bain,[60] is two miles northeast of LeMars, Plymouth county, in the west bank of Deep creek, in the west half of the southwest quarter of section 2, and shows four feet of blue-black clay shale belonging to the Graneros member of the Benton formation, overlain by twelve feet of thin-bedded limestone and chalky layers of the Greenhorn member.[61] The other exposure, reported by Macbride,[62] is in the southeast corner of Sac county. It is really a number of small exposures in the slopes of Raccoon river valley extending about a mile in either direction from Grant City. The Dakota and the two lower members of the Benton are shown.

There is abundant evidence that the Cretaceous rocks underlie the drift of practically the whole of the area, for they are the first bedrock penetrated by every deep well that is known within the region. Ten to fifteen miles east of the region the east edge of the Cretaceous area is reached. Mississippian and Pennsylvanian rocks lie to the east. Mississippian limestone is exposed at Gilmore on the east line of Pocahontas county, and farther east along the Des Moines river valley the Pennsylvanian rocks are exposed.

To the north in Lyon county the Cretaceous rocks rest on the basal foundation of pre-Paleozoic rocks, but over all the region to the southeast they rest on the truncated edges of Paleozoic strata which in turn rest on the basal foundation. The records of several deep wells are shown in figure 63 and the structure of the bedrock in a north-south direction is shown in figure 62.

Geologic History of Northwestern Iowa.

PRE-PLEISTOCENE.

Proterozoic.—The earliest recorded event in the history of northwestern Iowa is the deposition of the sand from which the Sioux quartzite was formed. Long continued weathering with mature decomposition had affected the region from which the sand was derived, for nothing remains that might be decomposed with longer time. The sand was well worn in transit

[60]Iowa. Geol. Survey, Vol. VIII, p. 332.
[61]Bain interpreted this section as Niobrara over Benton, but the divisions then considered Pierre, Niobrara and Benton were later shown to be the three members of the Benton.
[62]Iowa Geol. Survey, Vol. XIII, pp. 525-531.

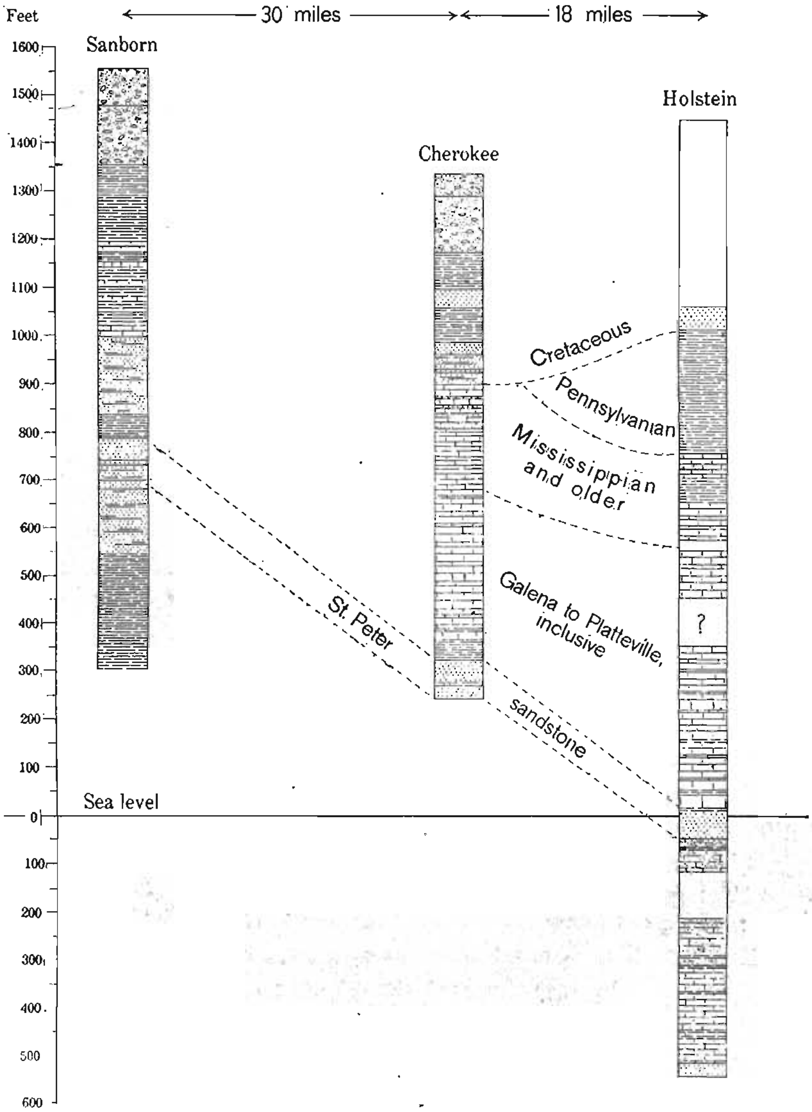


FIG. 63. Columnar sections of deep wells at Sanborn, Cherokee and Holstein. (Norton, Iowa Geological Survey, volume XXI, page 1006.)

and well sorted before or during deposition. The waters were shallow, and at many places the sand was deposited in cross-bedded layers and the shallow bottoms were rippled by the motion of the water. At times, sand deposition gave place to silt deposition, and at other times to gravel deposition. These deposits were later consolidated to sandstone, shale and conglomerate, and finally to quartzite, slate and quartzite conglomerate.

Some time after the formation of the Proterozoic rocks igneous material was intruded into them and this forms the igneous horizons penetrated by the deep well at Hull, as well as the igneous rocks exposed in the valley of Split Rock creek at Corson, South Dakota, and in the Big Sioux valley northeast of Sioux Falls. This intrusion took place deep beneath the surface under high temperature and pressure, and cooling was sufficiently slow to allow the formation of a coarse, wholly crystalline rock. Subsequent erosion has brought the surface down to the horizon of these deep seated intrusions.

Paleozoic.—The Paleozoic history of northwestern Iowa is only partly known. Deposition took place over most of the region during late Cambrian and Ordovician times (figure 63), and again during the Mississippian period, but in Middle Paleozoic time the region was probably land. These early and late Paleozoic seas extended northwestward as far as southern and eastern Lyon county and may have entirely covered the quartzite area (Sioux island). The sediments deposited included all the usual materials, sand, mud and calcareous ooze, and the common sedimentary rocks resulted from their cementation.

Mesozoic.—Following the late Paleozoic deposition the region again became land and remained so through the early part of the Mesozoic era, but in the Cretaceous period the great plains area of deposition spread eastward until it included the western half of Iowa. During the Dakota epoch the deposits were sand and mud, deposited on plains or in marshy areas. Then followed the Colorado epoch, when the areas of deposition were more distinctly marine. It began with the deposition of about fifty feet of mud which now forms the Graneros shale member at the base of the Benton. The seas then gradually became clearer, and the muds were mixed with, or even gave place to calcareous oozes, the whole accumulating in sufficient thickness to form the thirty foot Greenhorn limestone member of the Benton. During this stage abundant marine life existed and left its remains in the limestone. Mud deposition again succeeded and the material that now forms the Carlile shale was deposited. No rocks of the Niobrara formation, the upper part of the Colorado series, are known within the region, but they exist fifteen or twenty miles to the west. Deposition in northwestern Iowa probably ceased with the Colorado epoch, at the close of which there was a general restriction of the Cretaceous seas of the Great Plains. The Cretaceous deposits covered at least part of the Sioux island and may have completely buried it.

The erosion which followed the withdrawal of the Cretaceous seas probably continued uninterruptedly, except locally, to the Pleistocene. It exposed the Sioux island, wore back the edges of the Cretaceous deposits and removed the upper part of these rocks from all of the region. The pre-Pleistocene topography of northwestern Iowa probably had considerable relief and was probably in the mature stage of the erosion cycle.

PLEISTOCENE.

Nebraskan.—After the long interval of erosion from the Cretaceous to the Pleistocene, a change of climate took place and there alternated in the northern part of North America, times when great ice-sheets developed and spread southward into the upper Mississippi basin, and times when the ice disappeared entirely from this region. The first of these ice-sheets was the Nebraskan, the oldest ice-sheet known in the Mississippi basin. It covered the whole of western Iowa and pushed southward into Missouri.

The Nebraskan ice-sheet gathered material from all the formations over which it passed, igneous, metamorphic and sedimentary, but the most important source of the material which was left in northwestern Iowa, was the shales of Cretaceous age which covered eastern North and South Dakota, western Minnesota and western Iowa. This source explains the very compact, somewhat calcareous clay, almost free from grit and pebbles, which characterizes the Nebraskan till. The thickness of the drift deposited was probably 100 to 200 feet in many places.

After the Nebraskan glacial epoch the ice disappeared entirely from this region and the Aftonian interglacial epoch followed. Evidence exists in southern Iowa and as far north as

Crawford and Carroll counties to prove that the Nebraskan till surface remained for a long time undissected and that there was developed on it, chiefly by chemical weathering, a zone of gumbotil (page 416). It is probable that the same conditions existed and that the same gumbotil zone was developed over northwestern Iowa. Stream erosion then dissected the Nebraskan drift plain. During this time some large gravel deposits (Aftonian) accumulated along many of the larger valleys farther south in western Iowa, but within our region there appears to have been little gravel deposition at this time. Along the Little Sioux valley through Cherokee county where a number of exposures show the Nebraskan-Kansan contact, Aftonian gravels are not present.

Kansan.—After a long period of deglaciation, climatic conditions changed again to those favorable for glaciation, and the Kansan ice-sheet developed. This was the greatest of the ice-sheets which invaded the Mississippi basin. It covered most of Minnesota and Iowa, eastern North and South Dakota, and eastern Nebraska, and spread southward over northern Missouri and northeastern Kansas. Northwestern Iowa was 300 to 350 miles inside the southern margin of this ice-sheet at the time of its maximum extent, but only 50 to 100 miles east of the west margin. The thickness of the ice in this region was great and increased to the north and east. If the average distance which the ice traveled after crossing our region be taken as one hundred miles, and if an average gradient of fifty feet per mile be assumed for the first twenty-five miles back from the edge, and ten feet per mile for the remaining seventy-five miles, a thickness of two thousand feet is obtained. As the distance and gradients assumed above are conservative, we may safely assume that our region was buried beneath ice which probably was something like half a mile thick.

Little is known concerning the pre-Kansan topography of northwestern Iowa, but it probably was mature and of moderate relief. The chief surface formation was the Nebraskan till, although in the larger valleys, Aftonian gravels may have existed and locally the bedrock probably was exposed. Large quantities of Nebraskan till were plowed up by the Kansan ice-sheet and mixed thoroughly with the material already carried, becoming thereby part of the Kansan till. Some smaller masses of Nebraskan till were inclosed, without mixing, in the Kansan till. At some places the surface of the Nebraskan till was plowed up, but the material was only partly mixed with the Kansan till and so formed a transition zone from one to the other.

As the Kansan ice sheet advanced, great floods of water loaded with debris flowed out from its front and at a short distance from the ice-front began to drop their load of gravel and sand. With farther advance of the ice-front some of these deposits were plowed up and the sand grains and pebbles were mixed with the materials carried by the ice, making a more pebbly till. Some of the masses of the gravel, firmly frozen when plowed up, were incorporated as gravel bowlders in the till (pages 357 to 361). Any gravel deposit which existed in the region overridden by the ice might have been plowed up in this way whether it was outwash from the advancing ice or Aftonian or other gravels.

During the general stage of ice advance there were temporary withdrawals, and during the general stage of retreat there were temporary advances. As a result of these oscillations of the ice-front, gravel that was laid down just beyond the ice-front was later overridden and buried under till. In some places the oscillations were repeated several times and resulted in several alternations of the till and gravel as described for the Mill creek bluffs north of Cherokee (pages 372 to 376).

For the history of the time following the withdrawal of the Kansan ice-sheet we are again dependent upon the region farther south in Iowa. Over southern Iowa, as far north as Crawford and Carroll counties, the even drift-plain left by the Kansan ice-sheet remained for a long time undissected and on this plain there was developed a gumbotil zone (page 332). It is believed that a similar gumbotil zone was developed also over northwestern Iowa (pages 332 to 334). The development of these Nebraskan and Kansan gumbotils must have required a very long time and our conceptions of the Aftonian and Yarmouth intervals must be lengthened to make allowance for them.

Following the development of the gumbotil, the Kansan drift-region was elevated and erosion began. In southern Iowa this erosion has lowered most of the country below the gumbotil plain, but has left a few remnants. In northwestern Iowa erosion is believed to have reduced all the country below the level of the original plain and to have removed every remnant of the gumbotil (page 332). This erosion also removed the leached zone of Kansan till which was developed below the gumbotil. In this way the absence of a leached zone of Kansan till in northwestern Iowa is explained (page 338).

As the surface was lowered by erosion the gravel masses inclosed in the Kansan till were exposed. Because of the greater porosity of the gravel, these masses are more resistant to erosion than the inclosing till and they have come to be low gravel hills or mounds (page 362 to 372).

After this erosion had progressed well toward its present stage, gravel accumulated in most of the valleys of the region, forming the deposits which have been described above as valley gravels. The material for these gravels is believed to have been released by the erosion of the Kansan till (pages 411 to 414).

After the deposition of the valley gravels and probably soon thereafter, the entire Kansan drift-region was covered with a mantle of loess, the material for which was derived chiefly from the valley flats on the west line of the state. The thickness of the loess decreases eastward from twenty to thirty feet near the Missouri river to two to four feet in the eastern part of the Kansan area. Within the valleys the deposit formed on the valley gravels was not the true loess but a loesslike clay that is the time equivalent of the loess.

The interval of time from the Kansan to the next ice invasion of northwestern Iowa (Wisconsin) includes the Yarmouth, Sangamon and Peorian interglacial and the Illinoian and Iowan glacial stages. The Kansan gumbotil probably was formed chiefly during the Yarmouth stage. The dissection of the region and the accumulation of the valley gravels was completed by Iowan time if the loess is of Iowan age (page 357). Since the loess was deposited it has been leached to a depth of four to six feet and has been removed or re-worked on many of the steeper slopes.

Wisconsin.—During the Wisconsin ice-epoch a lobe of ice seventy to eighty miles wide pushed down across northcentral Iowa, two-thirds of the distance across the state. The west edge of this lobe lay across the eastern part of our region (pages 256 to 292 and Plate XV). This boundary makes several abrupt changes of direction, as east of Dickens and east of Milford, which are believed to be at the angles where minor lobes joined or overlapped each other. The exact history of these lobes, which were either contemporaneous or followed each other closely, will be known only after a thorough study of the Des Moines lobe not only in Iowa but also in southern Minnesota.

In Minnesota the west margin of the ice pushed up to the crest of the Coteau des Prairies, the high divide between the Mississippi and Missouri drainage basins, and the drainage from the ice-margin flowed southwestward to Big Sioux river. The drainage from forty-five miles of this front flowed away by Rock river and its tributaries across Lyon county.

South of central Osceola county the ice-edge did not reach the great watershed, and the southeastward flowing streams were dammed by the ice-margin,and diverted to more westerly courses. The most important diversion was that of the Ocheyedan-Little Sioux system (pages 310 to 318), the waters of which were diverted farther and farther westward until they finally crossed the great watershed in the southwest corner of Clay county, and entered a valley extending southwestward to Missouri river. Since this course across the watershed carried the drainage from about a hundred miles of the ice-margin, and from about eight hundred square miles between the great watershed and the ice-margin, the erosion along it was rapid and the course across the divide was soon firmly established. There was also a rapid deepening of the valley, the present Little Sioux, which carried the waters southwestward, and these valleys were soon worn to approximately their present depths. As the ice withdrew from its maximum extent, other courses were opened up southward on the east of the great watershed, and the quantity of water carried by the Little Sioux was decreased. It was possibly at this time that erosion was replaced by deposition and the gravels within the narrows of the Little Sioux valley were deposited. After the final disappearance of the ice, the streams again became eroding streams, and have cut their present channels in the valley-filling or have locally removed it entirely from their valleys.

The Wisconsin ice-sheet left a drift surface that is characteristically glacial, with strong morainic topography locally. Very little modification of this topography has been produced by the erosion of post-Wisconsin time except along some of the larger streams, which have cut prominent trenchlike valleys (pages 327 to 330).

CHAPTER VIII

SUMMARY AND CONCLUSIONS.

The conclusions reached concerning the various subjects that have been treated in this report, generally have been stated in connection with the discussions of these subjects, but it may be serviceable to bring together here a brief summary of them. The reader is referred to the respective chapters for the fuller statement and the evidence.

Wisconsin Boundary.—The course of the Wisconsin boundary is traced in Chapter II (pages 255 to 293), and shown on Plate XV. This boundary is essentially as traced by Professor Macbride across Sac and Buena Vista counties, the changes made being of minor importance and due to more detailed work. The boundary was shifted two miles farther west just south of the Wall lake outlet in Sac county, was placed a little nearer Brooke creek in northwestern Buena Vista county, and was extended farther up into the angle formed by Brooke creek and Little Sioux river valleys. The boundary from the south line of Clay county northeast to Dickens is approximately as mapped by Professor Macbride in his section on "The Margin of the Wisconsin Drift" in the report on Cherokee and Buena Vista counties (figure 28, page 249).[63]

[63] Iowa Geol. Survey, Vol. XII, pp. 325-338, 1902.

This course, however, was not mapped as the boundary on the Clay county map or discussed in that report.[64] From Dickens northwest to the state line, the writer found the course of the boundary quite different from that shown by Professor Macbride either in the reports on Clay, Dickinson and Osceola counties, or in the section on "The Margin of the Wisconsin Drift" in the report on Cherokee and Buena Vista counties. This portion of the boundary has been discussed on pages 270 to 287.

The separation of the Wisconsin and pre-Wisconsin drift-plains of northwestern Iowa is based chiefly on physiographic grounds. South of our region where the Kansan drift is maturely eroded and well weathered, the separation is distinct; where strong morainic features appear along the Wisconsin border, the separation also is distinct; but where the region to the west is not eroded, and the margin of the Wisconsin drift is not morainic, the separation is a matter of difficulty. The data furnished by the drift and by the loess-covering accord with the physiographic separation. There is little outwash from the Wisconsin drift except along a few large valleys.

The so-called Altamont moraine of Wilder in western Lyon county is not a moraine, but part of the area so mapped is the eroded edge of the upland and part is on the terrace, which is here covered with Indian mounds (page 296). The Altamont moraine mapped by Wilder in northeastern Lyon county is not Wisconsin drift (page 363).

Kansan Drift.—All of northwestern Iowa west of the Wisconsin drift-boundary is assigned to the Kansan drift-region on the basis of the identity of the till and of the presence of a mantle of loess over the entire region. The absence of leached Kansan till in northwestern Iowa is explained by the removal of this leached zone by erosion of the entire region below the original level at which leached till may have formed.

The Loess.—The entire region west of the Wisconsin drift-boundary is covered with loess. In the southwest part of the region this is typical loess and is thick. To the northeast it thins to a mantle of only two to three feet and lithologically may

[64]Iowa Geol. Survey, Vol. XI, pp. 461-508, 1901.

not be typical loess, but it is the time equivalent of the loess. An equivalent loesslike clay overlies the valley gravels.

Nebraskan Drift.—The dark colored compact till which is exposed beneath the Kansan at many places along the Little Sioux valley in Cherokee county is Nebraskan till. There is, however, no development of Aftonian gravels, and only a few areas of Aftonian silt were recognized. The Nebraskan till probably underlies the Kansan till quite generally in northwestern Iowa, probably at many places forming the major part of the great thickness of Pleistocene deposits.

Drainage Changes.—The great watershed of northwestern Iowa in pre-Wisconsin time extended from the middle of the south line of Sac county, northwest across the Boyer valley and then followed the divide to the west of the Boyer valley instead of the one to the east as at present. The upper course of the Boyer then drained east to Raccoon river by way of the Wall lake outlet (pages 318 to 320).

Farther north, in western Buena Vista county, this watershed crossed the Little Sioux valley either to the divide west of Waterman creek or to the divide east of that stream and north of the Waterman creek basin it continued along the high divide of northcentral O'Brien and central Osceola counties, and northward along the Coteau des Prairies. The Ocheyedan-Little Sioux system above Spencer at this time continued east past Dickens to Des Moines river and the streams of western Clay county, and possibly Waterman creek continued southeast into the present Wisconsin drift by courses now obliterated (pages 313 to 318). The changes which brought about the present system occurred most probably in the Wisconsin ice-epoch, when the eastward and southeastward flowing streams to the east of the great watershed were obstructed by the Wisconsin ice, which spread westward nearly to the crest of the divide in western Buena Vista county, and which lay across the east end of the Wall lake outlet in southern Sac county.

Interbedding of Gravel and Till—An interbedding of gravel and till characterizes the Kansan drift of several exposures (pages 372 to 380). These deposits were formed by oscillations of the ice-front during the general stages of advance and retreat.

By these oscillations, gravel deposited just beyond the ice-edge may have been laid down on till only recently deposited and may soon have been buried by till. The freshness of the gravel and till of these layers shows that neither was exposed long at the surface before the next higher member was deposited.

Gravel Bowlders and Gravel Hills.—The gravel and sand masses included in the till (pages 357 to 361) are parts of frozen gravel deposits which were plowed up by the advancing ice-sheet. As is shown by the composition of the gravel, by the freshness of the material and by the clay-balls, most of these masses are of the same age as the inclosing till. They represent deposits made in front of the advancing ice-sheet, which a little later plowed them up (page 361.)

The gravel hills of the Kansan drift-region are included gravel bowlders which have been exposed at the surface by the removal of the inclosing till. They come to stand above the surface of the till by the relatively greater resistance to erosion of the porous gravel mass.

The Valley Gravels.—The valley gravels occupy valleys cut into the Kansan drift. The material for these deposits was released by erosion from the Kansan drift and was accumulated in the valleys during a period of time subsequent to the major erosion of the Kansan drift-plain and preceding the deposition of the loess.

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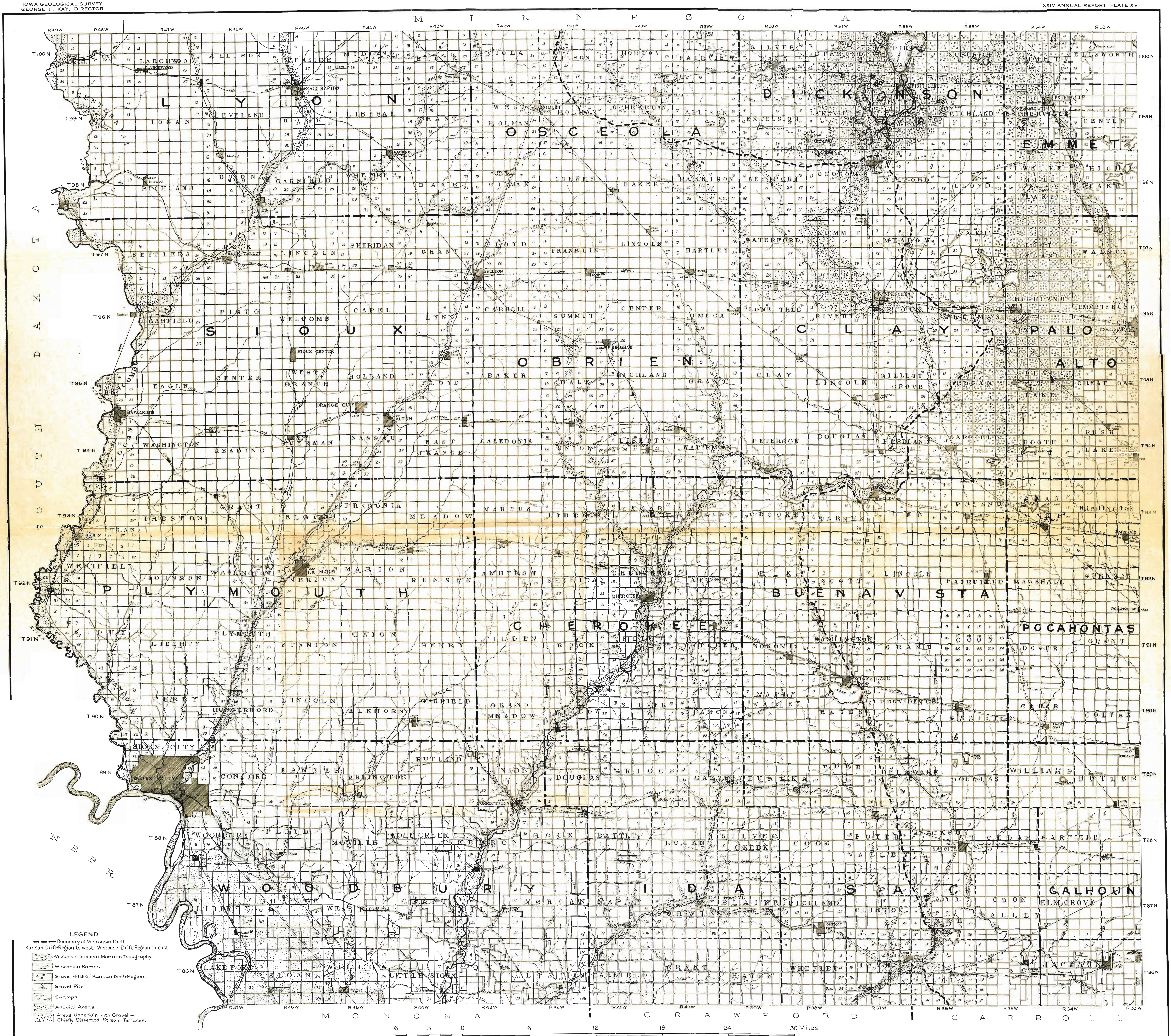

MAP OF THE PLEISTOCENE DEPOSITS OF NORTHWESTERN IOWA

BY J. ERNEST CARMAN, 1917