GEOLOGY OF WOODBURY COUNTY.

BY

H. FOSTER BAIN.

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CONTENTS.

INTRODUCTION.

LOCATION AND AREA.

Woodbury county lies on the western border, well toward the northern corner of the state. It is within sixty-five miles of the north state line; Lyon, Sioux and Plymouth counties intervening. The latter county lies directly north of Woodbury, while Ida borders it on the east, and Monona county on the south. On the west the Missouri river separates it from Nebraska, and the Big Sioux from South Dakota. The county lies at the head of the great bend in the Missouri river, where the stream changes its easterly direction and starts south on its journey to Kansas City. It includes a belt of country twenty-four miles wide stretching back from the river about thirty-six miles. Owing to the irregularities in the river boundary at the west, and the influence of correction lines in the northeast, it contains numerous fractional pieces of land, the total area being 860 square miles or considerably more than a half-million acres.

PREVIOUS GEOLOGICAL WORK.

The factor of location which so early made the chief city of the county a prominent trading post, its position at the turning point of the great river, has been equally potent in causing the early geological study of the region. The swinging of the river here to the extreme eastern limit of its valley has made numerous excellent exposures. These, in connection with the comparative ease with which they were visited, caused the earlier geological work in the region to start from this point. From the time when the Lewis and Clarke expedition ascended the river and collected fossils from these strata down to the present day every geologist who has worked on the region has studied the exposures near Sioux City. In the future as in the past, if one would most easily and surely learn of the stratigraphy, not only of northwestern Iowa, but of the whole upper Missouri region, he should begin his work with a study of these classic exposures.

A review of the observations of different workers in this region will be given in connection with notes on the different formations. It is perhaps sufficient to notice here that, of the official surveys of the state, the first or Hall survey, did not enter the region. During the second survey, both Doctor White and Mr. St John, studied the deposits of Woodbury county, though the short time allowed to the work did not permit much more than a reconnoissance. At the inauguration of the present survey the importance of the study of the exposures of this county as a key to the geology of the northwestern portion of the state was clearly recognized. During the first field season Doctor Calvin visited the county and his observations were recorded in the first volume of the present series of reports. This work so happily begun has since been carried on by other members of the survey.

PHYSIOGRAPHY.

TOPOGRAPHY.

The present surface relief of Woodbury county has been produced by the action of erosive forces. To get a clear conception of it one must first picture to himself an all but level, or very gently undulating plain, having a slight surface inclination to the south and west, and lying at a general elevation of about 1,400 feet. It should be conceived as composed of a material capable of catching and holding every line and curve carved upon it by the delicate tracery of a vigorous drainage system. Upon such a plain the rivers have worked, and in it they have carved their record of the past.

If a line be drawn from Sioux City to the south boundary of the county, about four miles west of Smithland, the land west of the line may be considered a second plain even more monotonously level than the one described, and lying some 300 feet below it. This second plain forms the bottom land of the Missouri and is, at its widest point in Woodbury county, some seventeen miles from bluff to river bank. On the Nebraska side there is a corresponding bottom land, beyond which may be seen the dark green of the Blackbird Hills and their northern continuation. Through this broad plain the Missouri wanders with many a crook and turn, marked on a summer day by clouds of dust gathered by the wind from its many lowlying islands and sand bars, with here and there a bright gleam of sunlight reflected from the swiftly moving waters.

This bottom land of the Missouri forms a marked topographic feature in the county, comprising, as it does, over 200

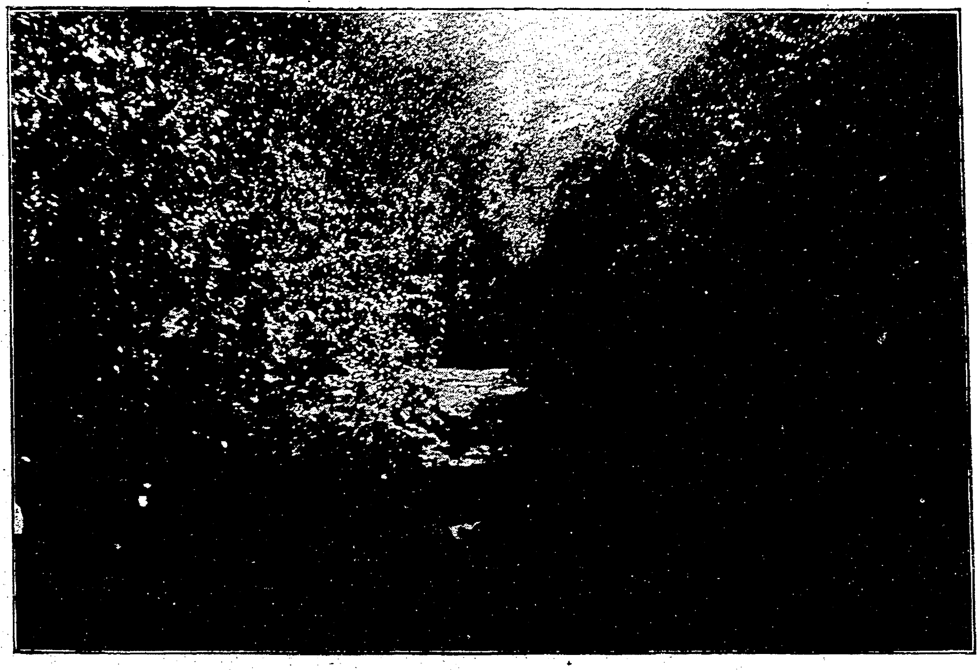

FIG. 32. Heavily wooded ravine in the loess region.

square miles, or nearly one-fourth of the entire area. The bluffs jut out upon it in a long, narrow spit at Sargents' Bluff, and the interior rivers of the county have cut their channels down nearly to its level and are now engaged, with their many minor tributaries, in reducing the whole area to this level. The work is new to them, and while the loess mantle cuts easily, it does not break down rapidly. The result is that the land along the streams presents an intricate and rugged series of erosional topographic forms. Deep, sharp-angled, steep-sided ravines lead back to abrupt earthern headwater bluffs over which, in rainy seasons, small streams dash merrily and fall foaming on the gravel below. Above such a fall may be seen the low swale of the upland, fully grassed over, and with slopes so gentle that, while serving for a catchment basin, they do not give current enough for the waters to cut away the sod. Below the thirty or forty foot bluff is a deep, narrow defile, fully wooded and usually dark, with sides almost too sharp for climbing, and with a gravel-strewn bed of a wet-weather stream at the bottom. Occasionally narrow terraces form a fit shelf for a wagon road, but usually they have themselves slipped out of place.

In the region between Smithland and Hornick, comprising the point of land between the Little Sioux and the Missouri

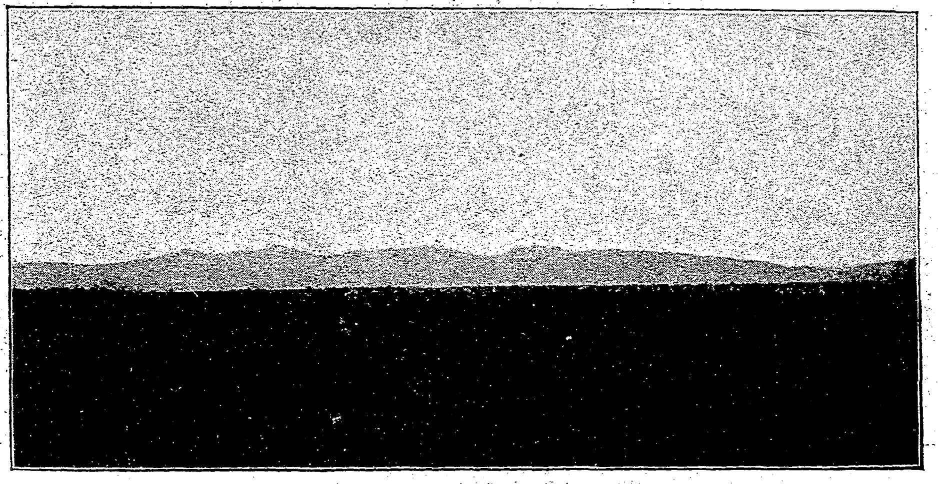

FIG. 33. Missouri escarpment; where the upland meets the lowland.

bottom lands, the tributary streams have cut into the hills and converted them into a series of intricately connected ridges barely wide enough at times to form a pathway, and with the sharp loess contours so sloping on either side that, as one walks along the crest, he unconsciously begins to balance himself as on the comb of a house roof. More frequently, however, these paths are wide enough to serve for wagon roads, and a drive along these old, now unused trails affords an ever changing succession of views at once striking and picturesque.

At the edge of the great bluff, where the upland drops abruptly down and becomes the lowland, the side streams have at many points cut off isolated, or nearly isolated hills, such as Prospect Hill in Sioux City. These hills of circumdenudation stand out abruptly with their beautiful flowing lines and gracefully carved peaks, resembling in the soft, dim afterglow of a summer evening, nothing so much as the towers and turrets of ancient castles. The beauty of the topographic forms seen in the county is a result of the great thickness and peculiar character of the surface material, which is the well known loess. This deposit exhibits here, to a superb degree, its characteristic of receiving and retaining those soft lines and curves which mark an unstable topography. The gently flowing concave slopes found here would never occur, or would soon be lost, in any other save a loess-covered or a rainless region.

There are three well marked types of topography within the limits of the county, the upland plain, the Missouri flood

FIG. 34. Loess hill east of Hornick.

plain, and the intervening stream-cut areas. The first is normally the characteristic prairie or drift plain type of long, low, rolling swells, flattening out into occasional broad areas of absolute level, and never exhibiting sharp profiles. It is covered, where uncultivated, by the tough wild grass of the prairies, and is unforested except where trees have been planted. The second is an even more monotonous level plain in which the smaller streams lose themselves and convert large areas into swamp land. The larger rivers cut across the plain in ditch-like channels. Above its level are raised a few sand dunes which form points in the landscape, as do also the quiet lakelets or sleepy lagoons formed of half-filled, and slowly silting up reaches of the river's abandoned channel. It is a broad, monotonous plain, fenced off into huge cattle ranches of thousands of acres in extent, where the ranch-house forms a conspicuous feature of the view, and is of sufficient importance to become a special station on the railway.

Where the upland plain meets the lowland, and in the vicinity of all the streams which flow across the region, the beautiful and intricate topography already described has been developed.

TABLE OF ALTITUDES.

The following altitudes are taken from the profile of the various railways, the notes of the Missouri river commission, and of the city engineer; they are in the main as given by Gannett. The elevations in Sioux City are referred to a uniform datum line which is approximately 998 feet above sea level. This amount has been added to the figures obtained from the engineer's office.

STATION.	Altitude.	AUTHORITY.
Anthon	1119	Ill. Cent. Ry.
Correctionville	1108	C. & N-W. Ry.
	1129	Ill. Cent. Ry.
Cushing	1279	C. & N-W. Ry.
Danbury	1311	C. & N-W. Ry.
Hornick	1073	C., M. & St. P. Ry.
James	1145	Ill. Cent. Ry.
Luton	1086	C., M. & St. P. Ry.
Morning Side	1241	C., M. & St. P. Ry.
Pierson	1272	C. & N-W. Ry.
Rodney	1091	C., M. & St. P. Ry.

STATION.	Altitude.	AUTHORITY.
Moville	1155	C. & N-W. Ry.
Oto	1094	Ill. Cent. Ry.
Salix	1092	S. Cy. & P. Ry.
Sargent's Bluff	1103	S. Cy. & P. Ry.
Sioux City—		
City reservoir	1342	City engineer.
Engine house, First street	1098	City engineer.
Douglas street, near Twenty-fourth	1314	City engineer.
Twenty-eighth street, near Virginia	1292	City engineer.
Jennings street, near Thirty-sixth	1317	City engineer.
Mondamin hotel, east door	1104	City engineer.
Northwest corner High school grounds	1228	City engineer.
Prospect Hill, top	1281	City engineer.
Prospect Hill, top of sandstone	1097	City engineer.
Jones street and Seventh	1195	City engineer.
Jones street and Tenth	1205	City engineer.
Jones street and Eleventh	1217	City engineer.
Head of Bacon Hollow	1398	Barometer.
Depot	1104	C., M. & St. P. Ry.
Low water	1076	Riv. Com.
High water	1099	Riv. Com.
Perry creek	1094	S. Cy. & P. Ry.
Floyd creek	1080	S. Cy. & P. Ry.
Sloan	1084	S. Cy. & P. Ry.
Smithland	1076	Ill. Cent. Ry.

DRAINAGE.

Woodbury county is well watered and drained by numerous streams belonging to the Missouri river system. The Missouri river itself forms the greater portion of the western boundary of the county. In this region it flows in a broad valley from one and one-half to seventeen miles wide, cut down through the rock to a depth frequently eighty to one hundred feet below the present water level.

The sandstone at the foot of Prospect Hill rises twenty-one feet above the low water mark of January 29, 1871. The solid rock is encountered 43.90 feet below low water, at a distance of 30 feet from the edge of the river on an extension of Kansas street. At 280 feet from the river's edge the rock lies at 34.70 feet below the water. At the Chicago, St. Paul, Minneapolis & Omaha railway bridge the depth to rock is slightly greater. The stream has a wide flood plain lying about 300 feet below the general level of the prairie. The banks are made up of loose unconsolidated materials, the river in this portion of its course being entirely free from rocky bars. The approximate average width from Sioux City to the mouth of the Platte is at high water 820 feet, and at low water 650 feet.*

Its current at low water stage is two to three miles per hour, and in time of flood it reaches as much as ten miles. There are two regular floods, the first being in April and lasting but a week or ten days; it is quite violent and seems to come from the upper river. The June rise is generally higher and of longer duration, being influenced by local rains and general saturation of the soil. The bottom land near Sioux City is at times covered in part by the waters of the Missouri and its tributary streams. The loose nature of the banks and the rapidity of the current causes the stream to carry a heavy load of sediment.

It has been shown by Major Suter that the channel of the Missouri is in reality a series of inter-locking pools. The width of the river allows the formation in it of a series of bars, on either side of which is deep water. These pools are so arranged that the head of one is about opposite the middle of the pool on the other side of the bar. The water thus finds its way from pool to pool, cutting across the bars in narrow, shifting channels. The bars act, to a certain extent, as dams, and even in stages of high water their effect on the rapidity of the current is plainly apparent. They also force the current against the bank where eddies are generated and erosion becomes active. In those reaches of the river where the stream is too narrow to allow the formation of bars, its course is but little changed since the earliest surveys (1817); elsewhere the changes have been many.

The second largest stream in the county is the Big Sioux, which forms the western boundary of the county from the northwest corner to the mouth of the river near Sioux City.

*Suter: Improvement of the Missouri; House Ex. Doc., 46th Cong., 3rd Ses., No. 92, p. 9. Washington, 1881.

It is a stream of considerable size and has a fall in a direct line of about 1.4 feet to the mile, or probably not more than six inches to the mile following the actual course of the stream. Below Westfield, in Plymouth county, the stream has properly no valley of its own, but flows close along the eastern border of the larger Missouri valley. In Woodbury county it is bordered by sharp, high bluffs, of which Cedar Bluff is, perhaps, the best known, made up of the indurated Cretaceous rocks, in the lower portion, covered principally with loess. It is along this river that the greater portion of the best Cretaceous exposures in Iowa occur.

Below the mouth of the Big Sioux river there are but two streams which flow directly into the Missouri within the limits of the county. These are Perry creek and Floyd river. They reach the Missouri river within the limits of Sioux City, and have very largely influenced the character of the surface upon which the city is built. Perry creek rises in the southwestern portion of Plymouth county and flows in the general direction of the slope a distance of seventeen miles in a direct line, with a total fall of nearly 180 feet. The average fall, following the stream, is probably not far from five feet to the mile. The current is rapid, the valley is narrow, and the bluffs are composed of loess and drift.

The Floyd river rises in O'Brien county and, flowing across Sioux and Plymouth into Woodbury, enters the county about ten miles east of the Big Sioux. From this point it flows southwest to the Missouri, having within the limits of the county a total fall of twenty-three feet, or about 3.2 feet to the mile. It is larger than Perry creek and throughout most of its course flows through a beautiful alluvial valley one to two miles wide, bounded by low, rounded, drift covered hills. Near Sioux City, extending, indeed, beyond the Plymouth-Woodbury line, there are exposures of Cretaceous.

Big and Little Whiskey, Elliott and Camp creeks are smaller streams flowing nearly south, and losing themselves upon the Missouri bottom in a slough now drained into the west fork of the Little Sioux. This latter stream flows across the county in a narrow, steep-sided valley lying from 100 to 180 feet below the general level of the plain. It cuts through the bluffs and comes out upon the Missouri bottom land near Holly Springs. Mud creek, and eventually Whiskey creek, drain into it from the west, while from the east it receives Wolf creek, itself an important stream with numerous tributaries.

The Little Sioux river is one of the larger and more important rivers of northwestern Iowa, having its source in Minnesota and falling over 500 feet to its mouth in Monona county. The greater portion of this descent is made before the stream enters Woodbury county. A little less than a mile below Correctionville, it is only nine feet above the Missouri river at Sioux City directly west. In a direct line the fall of the river in the county is about two feet to the mile, but by the stream it is probably more nearly three-fourths of a foot per mile. The valley is from one to two miles wide and is bounded by steep bluffs 300 to 400 feet high. In the lower portions of the river's course the bluffs show the presence of loess only; farther up the stream sandy gravel and drift, topped by a thin veneer of silt-like loess, is seen. The stream has evidently cut its channel down to grade and is now engaged in widening its valley.

The river, with its smaller tributaries, drains in this county an area of about 216 square miles. Within the county it receives from the west Pierson and Rock creeks, and from the east Bacon, Wright, Parmelly and Miller creeks. Eventually it receives also the waters of the West Fork and its tributaries, as well as of Maple river. Maple river is, within this county, independent of the Little Sioux. It cuts across the extreme southeastern corner of the district for a distance of about seven miles, draining nearly seventy square miles of the county. It receives, within the county, Reynolds and Koker creeks.

STRATIGRAPHY.

General Relations of Strata.

The rocks of Woodbury county belong to two distinct and widely separated periods between which is an important time break. The underlying indurated beds are of Cretaceous age. Above these, and concealing them except at a very few points, is a heavy covering of Pleistocene deposits consisting for the greater part of loess. Between the loess and the uppermost Cretaceous beds are the gravels and boulder clays of the drift, as well as certain obscure sands and clays whose exact relations are not very clearly defined.

The following table represents synoptically the different formations present.

Classification of Formations.

GROUP.	SYSTEM.	SERIES.	STAGE.	SUB-STAGE.
Cenozoic.	Pleistocene.	Recent.		Alluvium.
		Glacial.		Loess.
			Kansan.	Drift.
	?			Riverside sands.
Mesozoic.	Cretaceous.	Upper.	Colorado.	Niobrara chalk. Benton shales.
			Dakota.	

GENERAL GEOLOGICAL SECTION.

The greater part of the exposures of these beds may be seen in the immediate vicinity of Sioux City. A complete section may be found in passing from Sargent's Bluff to Cedar Bluff. Such a section would show the following beds.

		FEET.
16.	Loess of usual character, variable in thickness	50
15.	Clay, plastic, brown; weathering yellow along joints, usually free from grit, pebbles rarely found	6
14.	Gravel, drift pebbles; not always present, varying greatly in thickness	10
13.	Sand, fine, white, even-grained; with occasional small, granitic pebbles; no distinctively northern gravel	12
12.	Limestone, thinly bedded, containing numerous shells of *Inoceramus labiatus* and with interbedded chalk layers	50
11.	Shale, buff, sandy, with layers of sandstone one to two inches thick and with ferruginous concretions	18
10.	Shales, drab to dark blue, fine-grained, argillaceous	22
9.	Sandstone, fine, white, soft	4
8.	Shale, drab, fissile	12
7.	Lignite, impure, two to three inches	¼
6.	Sandstone, coarse, yellow, quartzitic	7
5.	Shale, clayey, dark blue to drab	12
4.	Sandstone, fine-grained, homogeneous, white	25
3.	Lignite, more or less earthy, usually dark purple	1½
2.	Shale, variegated, brilliant orange to olive green, with beds of fine sand and ferruginous concretions containing plant remains	18
1.	Shale, sandy, reddish, becoming drab to orange below, and containing plant remains	25

Of the above section, numbers 1 to 4 inclusive are exposed at Sargent's Bluff. Numbers 4, 5 and 6 make up the Prospect Hill section. Numbers 6 to 11 inclusive may be seen at Riverside. Numbers 10 to 12 are particularly well seen at Cedar Bluff; lower beds also occur there. Numbers 13 to 15 may be seen in the gravel pits at North Riverside.

Numbers 1 to 9 inclusive may be referred to the Dakota. Numbers 10 and 11 make up the Benton, and number 12 represents the Niobrara. Number 13 is of uncertain age; 14 to 15 represents the drift beds, and 16 is later.

PRE-CRETACEOUS STRATA.

Strata older than the Cretaceous are not exposed within this county, and hence their presence and character can only be known from borings and from studies of neighboring outcrops. North of Woodbury county, in the region surrounding Sioux Falls, there are numerous exposures of the Sioux quartzite, a formation probably of pre-Paleozoic age. Toward the east, the limestones and associated beds of the Carboniferous and earlier Paleozoic systems appear. South of Woodbury is found the latest phase of the Carboniferous as developed in Iowa. The beds of this system are exposed as far up the river as De Soto, and there pass below the Cretaceous.

The oldest strata exposed at the surface in northwestern Iowa and adjoining region is the Sioux quartzite. This has been referred to the Algonkian system, and is considered as pre-Paleozoic in age. There is little reason for believing that before the latest Cretaceous it was ever entirely below sea level, and it may not have been altogether covered even then. It has formed, from earliest times, a peninsula or an island, which has been gradually sinking. The pre-Paleozic surface of this island has been shown by Todd* to have been exceedingly irregular. Certain gray granites referred to the pre-Paleozoic were encountered in the Sioux City well at a depth of 1,515 feet, or 355 feet below sea level, while at Le Mars similar beds occur 150 feet above sea level. At Pawnee City, Neb., gray schists were encountered at 620 feet above the sea level. At 785 feet below sea level the Omaha boring had apparently failed to pass through the Carboniferous. The quartz-porphyry at Hull, which probably belongs to the same series, lies at 878 feet above sea level, while at Sioux Falls the quartzite itself has an elevation of about 1,400 feet.

Apparently this old surface sank beneath the water at the same time that the isle of Wisconsin was rising, so that, whereas, in the case of the latter, the central core is surrounded by a series of belts of later formations of which the oldest is nearest the center, the reverse is true of the Sioux island. It seems that each succeeding formation overlapped

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* Am. Geologist, vol. XV, p. 64, Minneapolis, 1895.

the earlier one, and it was only in Niobrara times that the region as far north as Carson, S. D., was under water.

The following is the record of the strata passed through in sinking the deep well at Sioux City. It is in part based upon notes furnished by Mr. D. A. Magee, and in part upon an examination of the drillings as preserved by him. The elevation of the mouth of the well is, according to Todd, 1,160 feet.

NUMBER AND NAME.	Thickness	Depth.
14. Loess	60	60
13. Drift	25	85
12. Shale	54	139
11. Sand and Sandstone	191	334
10. White sandstone	100	434
9. Gray sandstone	110	540
8. Sand and gray limestone alternating	115	655
7. Limestone, gray and white	150	805
6. Limestone and shales	445	1250
5. Sand, red above	25	1275
4. Sand and marl	45	1320
3. Limestone	190	1510
2. Hard brown rock	15	1525
1. Micaceous schist	589	2011

It seems impossible definitely to correlate each of the members of the section. Numbers 13 and 14 can, of course, be placed in the Pleistocene. It seems most probable that the base of number 9 marks the lower limit of the Cretaceous. Number 1 and probably number 2 belong to the pre-Paleozoic. Just what portion of the Paleozoic is represented by beds 3 to 8 cannot be certainly stated.

The well diggings at Sioux City and Le Mars show, between this underlying pre-Paleozoic complex and the Cretaceous beds, the presence of a series of limestones which have been usually referred to the Carboniferous. Such a series is usually found in wells drilled throughout the region. Whether these beds represent the Mississippian or some later portion of the Carboniferous cannot be definitely stated. It is even probable that they, in part, represent still earlier beds of the Paleozoic.

That there must have been at some time during the Carboniferous a shore line surrounding the Sioux island is obvious; that such a shore line would afford favorable conditions for the formation of coal is probable; but as yet this old shore line has not been found, and it is not at all certain that it ever will be. Between the close of the Paleozoic and the opening of the Mesozoic this entire region suffered very heavy erosion, and by far the greater portion of the Carboniferous beds under this region seem to have been swept away.

STANDARD SECTIONS.

Among the various natural exposures in the county a few have been selected which together represent all the beds

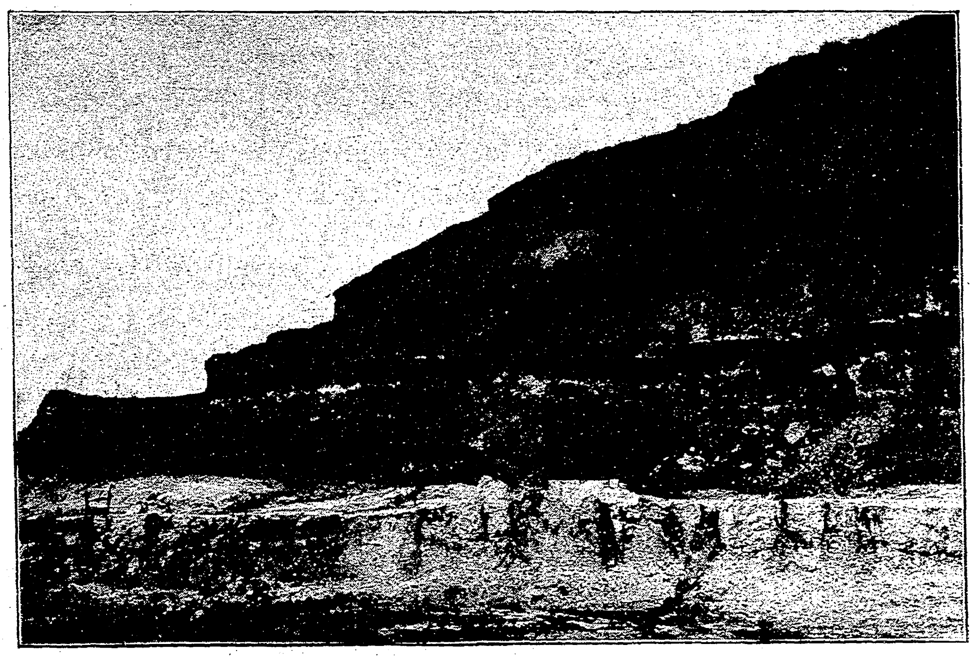


FIG. 35. Dakota formation, showing clays, lignite and sandstone, capped by loess; Sargent's Bluff, Woodbury county.

exposed at the surface, and which may be combined to make the general section already given. The lowest strata exposed within the limits of the county may be be seen in the well known outcrop at Sargent's Bluff, seven miles south of Sioux City.

SARGENT'S BLUFF SECTION.

		FEET.
5.	Loess, thickening back from the river and forming bold bluffs, 100 to 150 feet high	40
4.	Sandstone, fine-grained, light buff to white above, coarse, orange-yellow below	25
3.	Lignite, more or less earthy, usually of a dark purplish hue	1½
2.	Shale, variegated, brilliant orange to dark olive green, with interstratified beds of fine white sand and thin bands of ferruginous concretions containing plant remains	18
1.	Shale, sandy, reddish, becoming drab to orange below, and containing large ferruginous sandy masses with plant remains	25

Number 4 of this section forms the lowest member of the Prospect Hill section and occurs just below the surface at North Riverside. A section at the latter point, including the strata exposed in the pit of the Sioux City Paving Brick company and those found in borings at the pottery immediately above, is as follows.

		FEET.
15.	Shale, sandy	14
14.	Shale, drab, fissile	12
13.	Sandstone, impure, calcareous	1
12.	Shale, drab, fissile	16
11.	Sandstone, fine, white, soft	4
10.	Shale, drab, fissile	12
9	Lignite, impure, 2 to 3 inches	¼
8.	Sandstone, coarse, yellow, quartzitic	7
7.	Clay, white, plastic	19
6.	Sandstone, soft, shaly	14
5.	Clay, clear, drab	2
4.	Shale, argillaceous, very hard	4
3.	Fire clay	2
2.	Sandstone, hard, ferruginous	3
1.	Clay, fine, clean	16

Numbers 8 to 15 of the above section may be seen in the clay pit at the brick plant mentioned. Number 7 is exposed in a tunnel near by and was passed through at the pottery. The strata below this bed were found in the explorations at the latter place. Of the section, numbers 12 to 15, are referred to Benton; the lower beds, with all of the Sargent's Bluffs section, may be referred to the Dakota.

North of Riverside, the strata rise a little, and at Cedar Bluff, the best and most noteworthy exposure in the county, the corresponding beds appear a few feet higher above the river. The section here, as measured by corrected barometric readings, is as follows.

CEDAR BLUFF SECTION.

		FEET.
9.	Loess	30
8.	Limestone, thinly bedded, exposed in slope above; actual exposure, 20 feet, total limit	50
7.	Shale, buff, sandy, with layers of sandstone one to two inches thick, and ferruginous concretions	18
6.	Shale, drab to dark blue, fine-grained, argillaceous	22
5.	Sand and lignite mixed	1½
4.	Sandstone, white, calcareous, loosely consolidated	10
3.	Shale argillaceous, sandy in part, drab to blue	15
2.	Sandstone, white to orange, coarse-grained, with ferruginous concretions	10
1.	Shale, variable, largely arenaceous; imperfectly exposed	30

Number 7 of this section is number 15 of the Riverside section, and number 2 is apparently number 7 of that section, and may be examined at a number of exposures between the two points. While number 4 of the Cedar Bluff section and number 11 at Riverside occupy the same horizon, it does not seem that they are directly connected. At Cedar Bluff the Dakota includes numbers 1 to 5; the Benton is shown in 6 and 7, and the Niobrara in 8.

Above the Cretaceous, and below the loess and associated glacial deposits, is a sand bed, well shown in the pits northeast of the Brugier bridge at Riverside.

SAND PIT SECTION.

		FEET.
4.	Loess, usual character, variable thickness	30
3.	Clay, plastic, brown; weathering yellow along joints, usually free from grit; pebbles rarely found	6
2.	Gravel, erratic drift pebbles	½
1.	Sand, fine, white, even-grained, with occasional small granitic pebbles, no distinctly northern gravel	12

In the greater number of exposures throughout the county these beds are absent, the loess resting directly upon the Cretaceous, or with only an occasional thin layer of gravelly drift intervening.

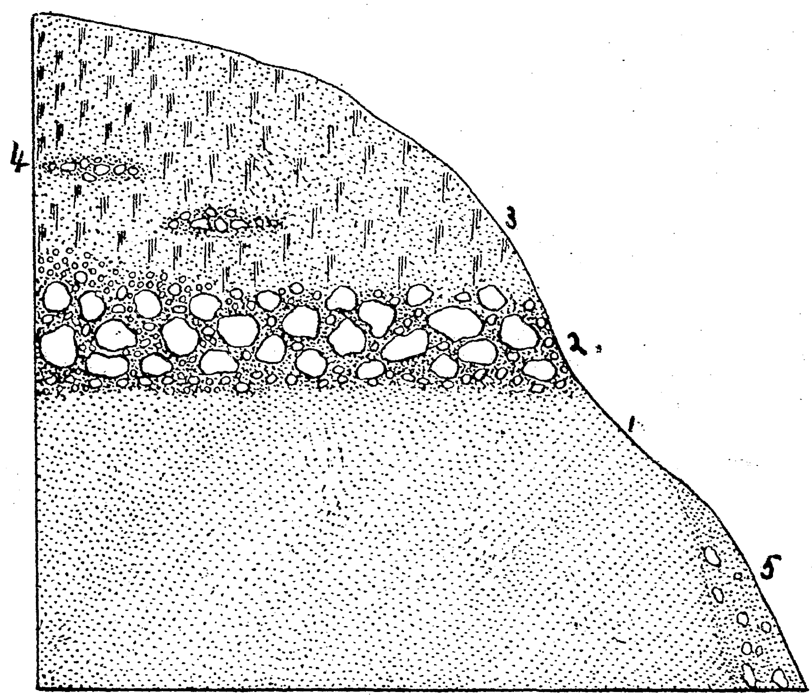


FIG. 36. Sand pit at Riverside opposite street railway station.

The character of these exposures and the relation of the drift to the loess are well shown in a small gravel pit opposite the Riverside Park street railway station.

5. Talus of loess.
4. Small lenses 4–14 inches in diameter, of coarse gravel and boulders in the loess.
3. Loess of usual character, exposed 15 feet.
2. Layer of large boulder erratics, varying from 2 inches to 1 foot in diameter, with sand in the interstices.
1. Sand cross-bedded, coarse-grained; grains $\frac{1}{12}$ to $\frac{1}{8}$ of an inch in diameter; really a very fine gravel, containing frequent pebbles $\frac{1}{2}$ to 1 inch in diameter, and occasional large, flat-sided, granitic boulders 8 inches or more in diameter, exposed 10 feet.

TYPICAL EXPOSURES.

The best natural sections exposed within the county are found along the Missouri and Big Sioux rivers. Of these, the Sargent's Bluff, North Riverside and Cedar Bluff sections have already been given.

At the foot of Prospect Hill, within the limits of Sioux City, and lying between Floyd river and Perry creek, is an exposure from which many of the early collections of the region came. As now exposed, it shows the following strata, all of which may be referred to the Dakota.

PROSPECT HILL SECTION.

		FEET.
3.	Sandstone, dark yellow, coarse-grained, with ferruginous concretions	10
2.	Shale, clayey, dark blue to drab	12
1.	Sandstone, fine-grained, homogeneous, white	25

Beyond this point the loess covers all the indurated rocks until North Riverside is reached. Here a good section may be obtained by following the electric railway down the hill. The beds seen are as follows.

		FEET.
10.	Loess	25
9.	Shale, drab, argillaceous; upper six inches colored by iron oxide	2
8.	Lignite, impure, brown, earthy	$\frac{2}{3}$
7.	Sandstone, fine, white, calcareous	6
6.	Sandstone, very ferruginous	$\frac{1}{2}$
5.	Shale, light colored, sandy	8
4.	Lignite, impure, earthy	1
3.	Sandstone, coarse-grained, yellow, with large, hard, quartzitic concretions	10
2.	Shale, drab	6
1.	Unexposed to water	20

A short distance north of this point is the Riverside section already given, and with which it may be readily correlated. Beyond the pottery the various beds are occasionally exposed, though no complete sections appear short of Cedar Bluff. The chalk beds appear in the hills northeast of the Brugier bridge (Tp. 89 N., R. XLVIII W., Sec. 14, Se. qr., Ne. $\frac{1}{4}$), but are not well shown for some distance farther up the river. The prominent sandstone band of the Cedar Bluff section (number 2) makes its apparance some distance below the bluff. It is shown at Reese's "granite" quarry (Tp. 89 N., R. XLVIII W., Sec. 11), where a portion has assumed the hard quartzitic facies already mentioned.

Away from the Missouri and the Big Sioux only a very few exposures are known. On the Floyd river, within the limits of Sioux City, the following section is seen (Tp. 89 N., R. XLVII W., Sec. 15, Ne. qr.).

		FEET.
9.	Loess	15
8.	Clay, yellow, with small lime nodules and erratics	2
7.	Sandstone, soft, fine-grained, white	6
6.	Clay parting	½
5.	Sandstone as above	4
4.	Clay	½
3.	Sandstone as above	8
2.	Clay, blue, shaly, mixed with sand	2
1.	Sandstone, white to orange; heavily cross-bedded	20

On the east side of the same stream, extending up to and slightly beyond Leeds, the chalk beds are occasionally exposed. Near Climbing Hill P. O., on the west fork of Little Sioux (Tp. 87 N., R. XLV W., Sec. 16), there is an obscure exposure of Niobrara. At one point in the bluffs, fronting the Missouri bottom land (Tp. 87 N., R. XLV W., Sec. 36), a number of Inoceramus shells have been found. While no strata are as yet positively known to occur *in situ* at this point, it seems not improbable, from the abundance of the shells, that ultimately such may be found.

With the exception of the exposures mentioned, and a few on Perry creek, there are no known exposures of the indurated rocks within the county, and stream cuttings in other portions of the county show only the loess and associated drift deposits.

Geological Formations.

CRETACEOUS.

The rocks near Sioux City were among the first Cretaceous rocks to be studied in America, and the problems of the structure and divisions of the great interior Cretaceous formations were first attacked in this immediate region. It was here that Meek and Hayden's Upper Missouri Section, which has so long been the standard with which others are compared, was developed. Some of the facts first observed here were so totally at variance with all previous observations that it may well be believed that they were not accepted without a deal of controversy. The evidence, pro and con, received from a host of distinguished workers such careful consideration as has rarely been accorded to geological problems. Certain of these controversies were in their day quite famous, and were so intimately connected with the early growth of American geology that it may not be unprofitable to review them briefly.

In 1804-1805, Messrs. Lewis and Clarke ascended the Missouri river. In the course of their journey they noted the sandstone at Blackbird Hills* and the exposures near Ponca, calling the latter "Mineral Bluffs." Subsequently Nuttal and Long, the latter in 1820, in their journeys up the Missouri collected fossils from this region. At the time of these expeditions the Cretaceous as such had not yet been recognized in America. In 1833 Morton,† in speaking of the fossils collected by these expeditions, refers to them as "Marl fossils," though he had in 1828‡ published Vanuxem's recognition of the Cretaceous. In 1834, Morton assembled his various papers on the Cretaceous fossils and published his Synopsis of Organic Remains of the Cretaceous Group of the United States.§ In 1838, the Prince Neuweid‖ published notes on an

*Coues: History of the Lewis and Clarke Expedition, Vol. 1, pp. 72-86. New York, 1893.
†Am. Jour. Sci., (1), XXIII, 289. 1833.
‡Jour. Acad. Nat. Sci., Philadelphia, VI, 59-71. 1828.
§Philadelphia, 1834.
‖Reise durch Nordamerika. Coblentz, 1838.

expedition to the upper Missouri region made in 1832. On this expedition he collected a number of Cretaceous types.

In 1839, Nicollet visited this region, publishing his full report* in 1841, and a shorter paper† about the same time. The exposures visited by Lewis and Clarke, and by them called Mineral bluffs, he named Dixon's bluff. He noted as he thought four formations as follows.

D. Plastic clay deposit, divided by a stratum of carbonate of lime nodules, 200 feet.

C. Ferruginous clay of yellowish color, with septaria and selenite.

B. Calcareous marl, 30 to 40 feet.

A. Argillaceous limestone, containing *Inoceramus barabini* in great numbers and very much compressed, giving the rock a slaty appearance.

Numbers A and B of this section seem to represent the Niobrara as now known, while C and D are probably representative of the Pierre. The Benton seems to have been overlooked as well as the Dakota. The fossils collected by Nicollet were described by Morton,‡ while the chalk was studied by Bailey.§

In 1849 Evans, one of Owen's assistants, traveled through the region and collected fossils which were described in 1852.‖ In 1853 Meek and Hayden visited the Upper Missouri region on a collecting expedition for James Hall. In 1856 Hall and Meek¶ published as a result of this expedition the first section showing all five of the members present in their correct position. In the same year Meek and Hayden** published jointly their first paper on the region. In this the five members were recognized and referred to by numbers. This became the Upper Missouri section and underwent slight

*Sen. Doc., 26 Cong., 2nd Sess., Vol. V, pt. ii, No. 237 Washington, 1841.

†Am. Jour. Sci., (1), XLV, 153-156. 1843.

‡Proc. Acad. Nat. Sci., Philadelphia, I, 106-110. 1841.

‡Jour. Acad. Nat. Sci., Philadelphia, VIII, 207-227. 1842.

§Proc. Acad. Nat. Sci., Philadelphia, I, 75. 1841.

§Am. Jour. Sci, (1), XLI, 400-401. 1841.

‖Owen: Geol. Sur. Wisconsin, Iowa and Minnesota, pp. 195-196. 1852.

¶Mem. Am. Acad. Arts and Sci., V., N. S., 379-411. 1856.

**Proc. Acad. Nat. Sci., Philadelphia, VIII, 63. 1856.

changes from time to time. It was not until 1861* however, that they give names to the various members. The section then assumed practically its final form; Meek, in 1876† contenting himself with simply reproducing it.

DAKOTA.

The lowest rocks exposed within the limits of the county belong to the Dakota formation. Their character is well shown in the sections already described; they are predominantly sandstones and shales, the latter being frequently

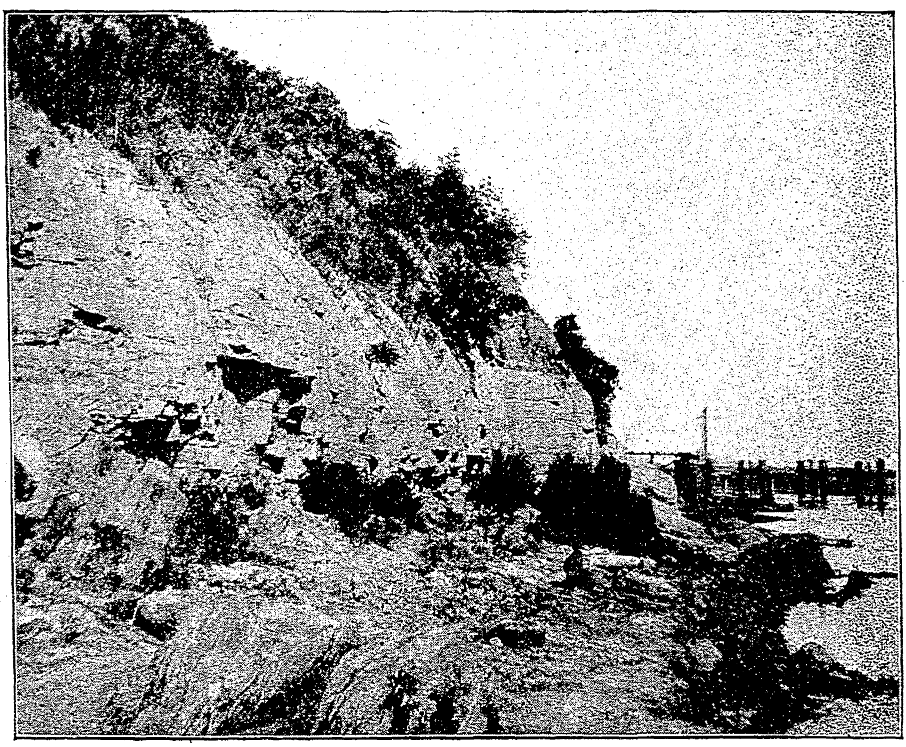


FIG. 37. Dakota sandstone at the foot of Prospect Hill, Sioux City. It was mainly from this exposure that the early collections of fossils were made.

arenaceous in character. The heavier sandstone beds seen on the Nebraska side farther down the river do not appear in the county. They are replaced by thinner sandstones and a greater proportion of argillaceous material. The sandstones occurring consist of two general types. The first is a light

*Proc. Acad. Nat. Sci., Philadelphia, XII, 415-447. 1861.

†U. S. Geol. Surv. Terr., (Hayden) IX, 24-25. Washington, 1876.

colored, buff to white, fine-grained, loosely-consolidated stone in which the cementing material seems frequently to be calcareous. It is stone of this kind which is found at the top of the Sargent's Bluff section, at the base of the Prospect Hill section, and which forms the upper of the two prominent sandstones at Cedar bluff. It frequently contains small pieces of charcoal, and in it are numerous leaves and plant impressions.

The second type of sandstone is seen forming the upper part of the Prospect Hill exposure, number eight of the Riverside section, and the lower of the two sandstones at Cedar bluff. It is coarse-grained, yellow to red in color, and has for cementing material iron, calcite and silica. The first is more usually predominant, and gives the stone a normal reddish tinge. At certain points these harder quartzitic masses, varying in size from a few inches up to several feet in diameter, resemble concretions. Their formation seems due to a secondary infiltration of calcite; the result of the process is a hard, quartzitic rock in which the original sand grains are surrounded by the secondary mineral. There has been no metamorphic change so as to obscure the clastic structure, which is as sharp as ever. Hayden and the earlier explorers called attention to these masses as a source of building stone, but the limited quantity of the material has prevented its large use.

The clays found in the Dakota are abundant and of great variety and adaptability; they are very rarely fossiliferous except where markedly arenaceous. At Sargent's Bluff the shale (No. 2) contains numerous ferruginous concretions arranged occasionally into well marked bands of red sandstone. In these are numerous plant remains. A collection from these layers recently determined by Mr. Paul Bartsch and Professor Macbride gave the following species.

Populus kansaseana Lesq.

Populus hyperorea Heer.

Salix proteæfolia, var. *longifolia* Lesq.

Myrica longa Heer.
Ficus magnollæfolia Lesq.
Ficus inæqualis Lesq.
Daphnophyllum dakotense Lesq.
Cinnamonium ellipsoideum Sap. and Mar.
Cinnamonium sezannense Watelet. ?
Diospyras primæna Heer.
Diospyras pseudoanceps Lesq.
Diospyras rotundifolia Lesq.
Inya cretaceæ Lesq.
Rhamus tenax Lesq.
Rhamus inæquilateralis Lesq.
Liriodendron giganteum Lesq. ?

In a preliminary report* a general section of the Dakota has been given. Since that work was carried on a rich Colorado fauna has been discovered in the clay pits at Riverside, and farther studies have made necessary several minor changes in this section. As now understood the Dakota comprises the beds assigned to it in the general section already given.

One of the most interesting discussions which occurred in the development of the geology of North America was that relating to the age of the Dakota. As has been seen the earlier workers, including Morton, Nicollet and Evans, had but slight knowledge of the Dakota, but correctly referred to the Cretaceous the higher beds which they did study. Hall and Meek† in their section, referred number 1 to the Cretaceous without question. Marcou,‡ from studies in the southwest, was led to infer an earlier age, and regarded the rocks at Ponca as New Red. Meek and Hayden§ in their first section say of number 1, that "it is not positively known to be Cretaceous," and again the same year‖ they remark that

*Iowa Geol. Surv., III, 109. 1895.
†Mem. Am. Acad. Arts and Sci., V, N. S., 405. 1856.
§Geol. Map N. Am., Ann. de Mines, (2), VII. 1855
‡Proc. Acad. Nat. Sci, Philadelphia, VIII, 63. 1856.
‖Proc. Acad. Nat. Sci., VIII, 267. 1856.

"number 1 may be Jurassic, or, perhaps, in part earlier." Hall* in 1857 divided the Cretaceous into three divisions, to the lower of which, number 1 of the Nebraska division is assigned.

Marcou,† in 1858, continued to refer the beds to the New Red. In the same year Meek and Hayden‡ unqualifiedly placed these rocks, as seen between Council Bluffs and Sioux City, in the "Lower Cretaceous." So far but few fossils had been found in them except plant remains. Sketches of several of the latter were sent by these authors to Professor Oswald Heer, but as his answer was delayed, the collection was referred to Newberry who pronounced the plants Cretaceous. Much to every one's surprise, Heer pronounced the forms Miocene. Marcou§ then, having previously assigned the rocks to the Jurassic,‖ maintained that Meek and Hayden had confused as one group the rocks from the Jurassic to the Miocene. Meek and Hayden¶ replied by showing that at many points the disputed beds were covered by strata containing well known Cretaceous forms. Newberry** recorded similar sections and further argued from the plant remains for the Cretaceous age of the beds in question.†† To the latter evidence Heer‡‡ replied, and while admitting the force of the other evidence, maintained that the flora was predominately Miocene in character. In 1863 Messrs. Jules Marcou and J. Capellini made an excursion to Sioux City for the purpose of studying the rocks in controversy.

The following year Marcou§§ announced his belief in the Cretaceous age of the Dakota, as the rocks were by that time

*U. S. and Mex. Bound. Surv., I, 134. 1857.

†Geology of North America, 143. 1858.

‡Proc. Acad. Nat., Sci., Philadelphia, X, 145-146. 1858.

§Letter on some points of the Geology of Texas, New Mexico, Kansas and Nebraska; addressed to F. B. Meek and F. V. Hayden.

‖Notes pour server a une description geologiqui des Montages Rocheuses, p. 20.

¶Proc. Acad. Nat. Sci., Philadelphia, X, 256-264. 1858.

¶Am. Jour. Sci., (2), XXVII, 219-227. 1859.

**Am. Jour. Sci., (2), XXVIII, 298-299. 1859.

††Am. Jour. Sci., (2), XXIX, 208-218. 1860.

‡‡Am. Jour. Sci., (2), XXXI, 435-440, 1861.

§§Bul. geol. Soc. de France, (2), XXI, 132-147. 1864.

called. In a later paper* he gives further details. In 1865 Meek† reviewed the controversy, and in 1867 Hayden‡ after reading the joint paper written by Capellini and Heer§ also discussed the subject.

Since that time the Cretaceous age of the Dakota has not been seriously questioned, though Lesquereaux‖ at one time suggested that the presence of a Miocene flora under a Cretaceous fauna might be due to some such curious condition as allows the survival of certain Mesozoic types of animal life in the deeper seas at present. In 1884 Gardner¶ maintained that the flora of the basal American Cretaceous is Eocene in character, and seemed disposed to the belief that this is an instance of persistence of Cretaceous types into Eocene time rather than of the earlier introduction of forms which later characterized the Eocene.

As has been said, the Dakota is predominately made up of sandstones and sandy shales. The sandstones frequently show heavy cross-bedding and are closely related to the overlying shales of the Benton. So close is this relation in fact, that Meek and Hayden** at one time, cautiously suggested that the Dakota might ultimately be found to be only a subdivision of the Benton, and White†† in his studies of the Iowa exposures was led to group all the strata below the Inoceramus beds in one division under the name of Woodbury shales and sandstones. Calvin‡‡ has interpreted the deposits as indicating continuous subsidence.

These views all accord in making the Dakota a brackish water or estuary deposit formed under influences connected with marine conditions. The presence, however, in the sandstones of numerous plant remains has caused the Dakota to

*Bul. geol. Soc. de France, (2), XXIV, 56. 1866.

†Am. Jour. Sci., (2), XXXIX, 157-174. 1865.

‡Am. Jour. Sci., (2), XLIII, 171-179. 1867.

§Mem. Soc. Helvetique des Sci. nat, XII, 1-24. 1867.

‖U. S. Geol. Surv. Terr. (Hayden), Ann. Rep. 1870, 377-385. 1871.

¶Brit. As. Adv. Sci., 54th. Meet., 1884, 739-741. 1885.

**Proc. Acad. Nat. Sci. Philadelphia, XII, 415-447. 1861.

††Geol. of Iowa, I, 289. 1870.

‡‡Geol. Iowa, I, 147-161. 1893.

be considered by many as non-marine or fresh-water. Marcou* advanced this idea, naming as a fresh-water form found in it *Cyrena Nova-Mexicana.* Capellini† held the same opinion saying: "The Cretaceous strata in the environs of Sioux City * * * may be divided into two distinct parts, one rich in leaves, a fresh-water formation * * *." White‡ says of the formation in general: "This formation is of non-marine origin * * *. In some districts the presence of Unio * * * shows that fresh water conditions prevailed. In other districts * * * forms indicate * * * brackish water, and in the southern and southeastern portion * * * fossils * * * show * * * the waters gradually changed from a fresh to a marine character."

On the other hand, the marine character of the deposits has not been without advocates. Thus Meek,§ in dissenting from Marcou, states his belief that *Cyrena Nova-Mexicana* of the former is *Cyrena arenaria* M. and H., which has been found with Axinea (Pectunculus), *Mactra siouxensis* and Pharella. Of these, Mactra and Pectunculus are well known marine forms, and Cyrena and Pharella indicate brackish water. From this, Meek was inclined to believe that the Dakota beds were indicative of estuary conditions. Hayden,‖ after quoting Capellini's opinion, says: "I would simply say I have always regarded it as marine, and I am sure this has been the opinion of my friend Mr. Meek. At any rate, we have found mingled with the leaves, at Sioux City, quite well preserved casts of *Pharella* (?) *Dakotensis*, *Axinea Siouxensis* and *Cyprina arenacea* shells peculiar to marine deposits." Hicks¶ has reported the discovery at Fairbury, Neb., of a very rich marine fauna in the Dakota. These forms have been examined by White**, who finds that they are non-marine. Todd††

* Bul. geol. Soc. de France, XXI, 132-147. 1864.
†Mem. Soc. Helvitique des Sci. Nat., XXII, 1-24. 1867.
‡ Bul. U. S. Geol. Surv., No. 82, 171. 1891.
§ Am. Jour. Sci., (2), XXXIX, 172.
‖ Am. Jour. Sci, (2), XLIII, 178.
¶ Proc. Am. As. Adv. Sci., XXXIV, 219.
** Proc. U. S. Nat. Mus., Vol. XVII, pp. 131-138. Washington, 1895.
†† South Dakota Geol. Sur., Bul. I, pp. 82-84. Sioux Falls, 1894.

has recently reviewed the subject and seems to think a marine or brackish water origin more probable.

It would seem probable that the fresh-water character of the beds has perhaps been too strongly insisted upon. Certainly it is true, as remarked by Todd, that it is easier to account for fresh-water forms in marine deposits than to account for marine forms in fresh-water beds. The presence of marine forms mingled with the leaves at Sioux City, as noted by Hayden, and the undoubted close relations between the Dakota and Colorado as seen here, would seem fair warrant for the belief that Meek's suggestion of estuary conditions is, here at least, a good one. The predominance of sandstone, its cross-bedded character, the presence of lignites, the occasional finding of marine forms, and the gradual transition upward into true marine beds, are all analogous to the conditions found in the lower coal measures of the state, where they have been repeatedly interpreted as indicative of marine shore conditions.

COLORADO.

Above the Dakota is a series of beds which are, on the whole, divisible into two parts. Of these the lower, which has been known as the Benton, or Fort Benton, is in Iowa a bed of argillaceous shale of a prevailingly drab color, and with a maximum thickness of about forty feet. It is not usually sharply separated from the underlying more sandy beds of the Dakota or the overlying calcareous beds of the Niobrara. Lithologically it is, as a rule, more closely connected with the Dakota, but paleontologically its affinities are with the Niobrara. The lower portion is seen in number 9, of the section at the Riverside Electric railway station, and it is better shown in numbers 12-15 of the North Riverside section at the Sioux Paving Brick works. Here it contains a thin, sandy layer, and occasionally calcareous nodules are found in a more or less regular band. In the Cedar Bluff section the Benton has its greatest thickness and is shown in two facies, a lower, more argillaceous, and an upper, more arenaceous, division. The upper layers of the latter division show the presence of *Inoceramus labiatus* Schloth., and the beginning of the chalk. There is, however, a considerable slope before the well marked chalk beds are clearly exposed.

The upper portion of the Colorado, the Niobrara, is shown at Cedar Bluff and on the tops of the hills northeast of the Brugier bridge. South of this point it is not exposed on the Iowa side of the Missouri, unless the locality in West Fork township already mentioned be excepted. On the Nebraska side of the river the beds are found near Homer, and Meek and Hayden* mention finding them thirty miles below the mouth of the Big Sioux. Lonsdale has recently found these beds exposed as far south and east as Auburn in Sac county. The Niobrara beds are predominantly calcareous, being made up of thin, shelly limestones with interbedded chalk. The limestone is well characterized by numerous fossils† among which in Iowa *Inoceramus labiatus* and *Ostera congesta* are easily most prominent. The limestone is usually crowded full of these shells. In addition to these forms, Mr. J. C. C. Hoskins‡ has found sharks' teeth on Perry creek (Tp. 90 N., R. XLVII W., Sec. 17), and St. John§ mentions fish remains as occurring at Cedar Bluff. The bones of marine saurians have also been found. Calvin‖ who has recently studied the chalk of the Niobrara, mentions a number of species of foraminifera as occurring near Sioux City.

In the pit of the Sioux Paving Brick Co., at Riverside, a number of characteristic Colorado forms have been collected from the beds referred above to the Benton. Among them may be mentioned *Inoceramus labiatus* Schloth., *Callista* (*Aphrodina?*) *tenuis* M. & H. and *Prionocyclas* sp. und.

In Meek and Hayden's Upper Missouri section five members were recognized.

*Proc. Acad. Nat. Sci., Philadelphia, X, 256-264. 1858

†See Staunton for a review of the Colorado fauna: Bul. U. S. Geol. Surv., No. 106. 1893.

‡See foot note: Proc. Am. As. Adv. Sci., XXXI, 1872, 191. 1873.

§Geol. of Iowa, II, 198, 1870.

‖Iowa Geol. Sur, III, 213-236. 1895.

5. Fox Hills, sandstones and shales.
4. Fort Pierre, blue argillaceous shales.
3. Niobrara, chalks and limestones.
2. Fort Benton, variegated shales.
1. Dakota, sandstones.

These divisions were differentiated largely on lithological and stratigraphical grounds, and as early as 1856 these authors remark of numbers 4 and 5 that they are "inclined to regard (them) as only well marked subordinate members of the same natural group*." So Meek,† in his final report, notes the fact that paleontologically there are only three divisions. The term Colorado was proposed by King‡ to include the beds previously known as Benton, Niobrara, and Pierre. It was later restricted by White§ so as to include only the Niobrara and Benton and is in that sense used here. White,‖ in his earlier studies of the Iowa Cretaceous used the terms Woodbury shales and sandstones and Inoceramus beds. Calvin¶ correlated these beds with the divisions as recognized by Meek and Hayden, and there seems now no need for the farther use of White's terms. The upper beds, known as the Montana formation, do not appear within the limits of Woodbury, though found in Sioux county farther north.

PLEISTOCENE.

The history of this region since the close of Cretaceous time falls readily into three periods, the preglacial, glacial, and postglacial. The first of these extends throughout Tertiary and into Pleistocene times, but inasmuch as the deposits made since the Cretaceous probably belong to the Pleistocene the whole may be considered here.

PREGLACIAL DEPOSITS.

During Cretaceous times the sea invaded Iowa successively farther and farther, the encroaching waters coming from the

*Proc. Acad. Nat. Sci., Philadelphia, VIII, 266. 1856.
†U. S. Geol. Surv. Ter., (Hayden) IX, pp. xxi-xxvii. 1876.
‡U. S. Geol. Surv. 40th. Par., I, 298. 1878.
§U. S. Geol. Surv. Ter., (Hayden), Ann. Rep. of 1876, 22. 1878.
‖Geology of Iowa, I, 289. 1870.
¶Am. Geol., XI. 300, 1893; and Proc. Iowa Acad. Sci., I, iii, 7, 1893.

west. At first there was the period of estuary and shore deposits marked by the Dakota. Following this came a time when the clays of the infra-littoral zone, which are seen in the Benton shales, were being laid down. This period which in Iowa does not seem to have been a long one, was terminated by the rapid incursion of the deep sea represented in the off shore deposits of the Niobrara. These waters swept far eastward, but apparently did not remain long. When the sea retreated there was a period during which Iowa remained perhaps but little elevated above the sea. At the same time the later Cretaceous beds farther west were being laid down. At the close of the Cretaceous came the remarkable uplifts and earth movements which elevated the Rocky mountains, tilted the plains, and gave birth to the major features of the drainage of the Mississippi valley. These movements affected profoundly the area under consideration. It was elevated from its previous low-lying position to a point considerably above sea level, and not unlikely a good many feet above its present elevation.

Sometime in the long period between the orographic movements just mentioned and the advent of the ice, the Missouri river cut its present greater valley, which is as has been said, a great, rock-bound trough, from three to seventeen miles wide, with drift and loess-veneered walls on either side. The Missouri, in part at least, cut down to a depth of from seventy to one hundred feet below its present low water level, and the same statement may be made respecting the minor streams. The erosion of the Missouri cut successively through the Niobrara and Benton beds, and deep down into the Dakota. As the major stream worked its way down step by step to lower levels, it carried with it the tributary streams until the whole drainage system was working on a plain considerably below the present. Here corrasion became inconsiderable and lateral degredation set in. The efforts of the streams were directed to broadening their valleys. This stage seems to have been a long one, and it was in that period that the wanderings of the river current, together with the usual tendency of river bluffs to retreat from the stream, led to the development of the now wide, but then perhaps wider, flood plain of the Missouri.

At some time in the period between the retreat of the Cretaceous sea and the advent of glacial conditons, at least a portion of Woodbury county was covered by a shallow lake. The deposits made at that time were noticed in giving the sand pit section. They consist of fine to coarse white sand containing occasional small pebbles, in the main granitic, with chips of wood and a few fossils. The pebbles found are of small size, water worn, and of such type that they might readily come from either the west or the north. There are, so far as a careful search reveals, no distinctively northern rocks present, and certainly no rocks showing ice action. The general character of the sand is much like that of the Neocene or Pliocene beds found a few miles west in Nebraska and South Dakota.

Similar beds occur at several other points in Iowa as well as in Nebraska and South Dakota. Todd*, who first described them, considered the beds to mark the eastern limit of Lake Cheyenne, described by King, and to be evidence of the persistence of that body of water up to glacial times. He mentioned finding Megalonyx remains in similar beds in Mills county. In 1890† he added certain notes on the distribution of the sand, mentioning it as occurring opposite Canton, S. D., and announcing its probable presence beneath the drift at Le Mars.

In the beds at Sioux City Mr. J. C. C. Hoskins found certain fossil teeth which, upon being referred to Professor E. D. Cope, were pronounced to be "three left superior molars of the horse, *Equus major* Dek., of Pleistocene age. It is entirely restricted to that horizon." These teeth, and the bones of the Megalonyx, already referred to, are the only fossils ever found in these beds. They may, however, be from

*Proc. Am. As. Adv. Sci., XXXVII, 202-203. 1889.
†Proc. Iowa Acad. Sci., Vol. I, pt. ii, 14-15. 1892.

different horizons, since the Mills county beds and the sands found at Riverside are not, so far as known, connected.

There is then, in the presence of these beds, evidence of a slight and probably short subsidence over this region occurring in earliest Pleistocene, or possibly beginning in later Neocene times. The evidence exhibited near Sioux City seems to favor the belief that this subsidence took place before the Missouri river channel was cut. The objection to this view is the great breadth of the valley both at Sioux City and at some points higher up the river. It seems not improbable, however, that the present width of the valley is a resultant of the soft character of the rocks of the region, rather than the expression of long time erosion. This seems all the more probable when one considers the greater carrying power of the river in glacial times.

If this be the correct interpretation, we would have then, in this region, a period of deposition followed by a period of stream cutting immediately preceding glacial conditions. The period of deposition, coming as it did in earliest Pleistocene or later Neocene, would be in a general way contemporaneous with the Lafayette deposition of the southern and eastern United States. The following of the deposition by a period of uplift, as evidenced by stream erosion, is also well in accord with the history of the earth movement as seen in other states. In this connection it is of interest to note that the stream cutting preceding the ice invasion is not peculiar to Woodbury county, but has left its traces in many other counties in the state. The records of numerous deep borings have shown the presence of preglacial channels similar in character to those which are now followed by the streams of Woodbury county, at many points.* These are not confined to Iowa, but have been found in many other states, and Mr. McGee† has pointed out that they may be traced from point to point until the region never covered by drift is reached. Here a similar set of trenches are found which may, in part

*Iowa Acad. Sci., II, 23-26. Des Moines, 1895.

†Communicated.

at least, be definitely referred to the post-Lafayette emergence. There would seem to be no good reason for separating these channels and, until a better correlation can be made, it would seem in place to consider the preglacial river channels of Woodbury and other counties in Iowa as the expression of the earth movement which terminated the Lafayette.

GLACIAL DEPOSITS.

Drift.—Woodbury county lies outside the Altamont moraine and within the area covered by the Kansan ice sheet. The deposits found within the county and referred to this period are not conspicuous, owing in part to the presence of the

FIG. 38. Ledge forming waterfall, Woodwarth's glen.

very thick loess and in part to the terraces along the river. Heavy beds of boulder clay, such as are commonly exposed in the southern and eastern part of the state, are occasionally reported from wells, but rarely exposed at the surface. The drift which is seen is thin and patchy, and frequently presents more or less strong indications of water action. The section previously given of a gravel pit at Riverside is a good example, though usually the gravel and sand are mixed together so that neither can be used without screening.

In Woodwarth's glen, just outside the county (Tp. 86 N., R. XLIV W., Sec. 17, Sw. qr.), an opportunity is afforded to get a section into the heart of the loess promontory lying between the Little Sioux and the Missouri. This glen is a narrow defile cut by a small stream, and running back well into the interstream area. It is steep-sided and heavily wooded, and throughout most of its extent nothing is seen except loess and a narrow terrace of modern wash dirt. Farther up the ravine, the drift beds which underlie the loess may be seen. At one point is a small cascade where the water falls some eight or ten feet. The section shown here is fairly typical, and is as follows.

		FEET.
6.	Loess of usual character above, sandy below	15
5.	Coarse gravel	1
4.	Boulder clay	1½
3.	Coarse, loose sand	5
2.	Sand, consolidated to a fragile sandstone	2
1.	Coarse sand	6

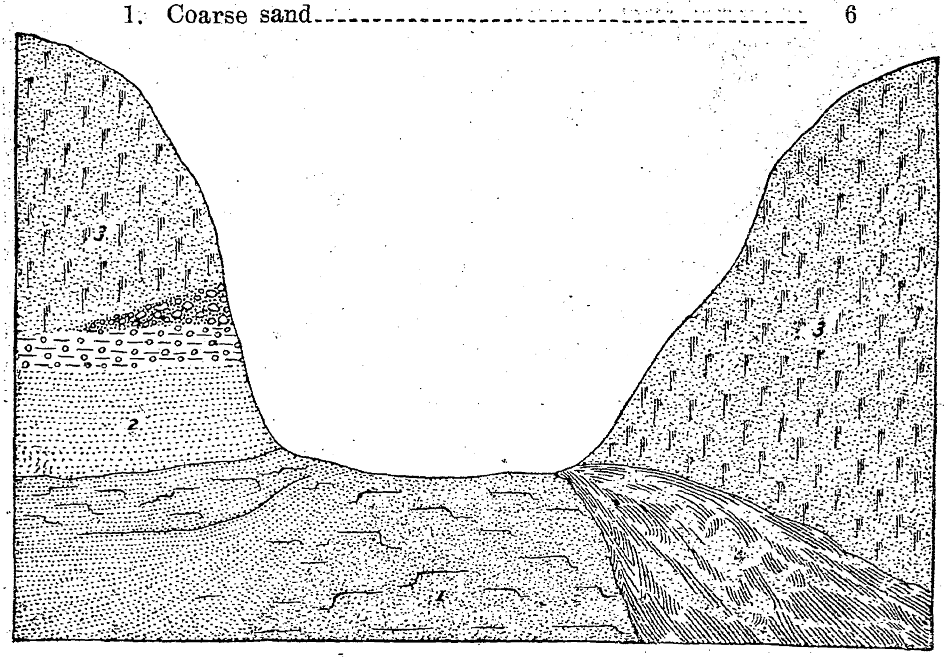


FIG. 39. Drift at waterfall in Woodwarth's glen. The numbers in the figure refer to the numbers of the section as follows: 1, No. 1; 2, No. 3; 3, No. 6; No. 4, represents a talus.

The sand forming the base of the section is coarsely bedded and loosely consolidated. The different members of the section do not maintain themselves over any great area, though the presence of the coarse sand is indicated at several points farther down the ravine, and a large number of boulders are found in the bed of the stream. At one point, a blue boulder clay is seen to be present, though its thickness could not be determined. The fall at the cascade is due to the induration of the upper portion of the sand layer, as shown in the figure. This induration is due to the cementing of the fine gravel and sand by a calcareous bond, apparently derived from the lime nodules, which are, as usual, abundant in the loess. That the water is heavily charged with calcium carbonate is shown by the calcareous coating on sticks and leaves lying near the foot of the fall. The rivulet is a wet-weather stream only, and derives its supply of water from drainage of the loess upland.

Near Anthon there is a second example of the secondary formation of lime conglomerate. In a small ravine (Tp. 87 N., R. XLIII W., Sec. 16, Nw. qr., Se. $\frac{1}{4}$) there is a well defined ledge of what is at first glance a limestone. A closer examination shows it to be made up of pebbles and coarse sand, cemented together by a calcareous cement. The consolidated stratum lies at the base of the loess capping the gravelly drift which is characteristic of the region, and the ledge of conglomerate is about eighteen inches thick.

On the west fork of Little Sioux, below Moville, little but loess is seen. At one or two points coarse, sandy gravels are exposed. Between the east and west forks of the same river similar beds are occasionally seen, and along the east fork gravel terraces are found. At most of the exposures near Sioux City the loess rests directly upon the Cretaceous rocks. Where drift deposits occur, they are very similar to the beds already described.

Along the loess escarpment, stretching southeast from Sargent's Bluff, there are occasional exposures of gravelly drift cropping out from beneath the loess. East of Hornick these beds have been opened up at one or two points for the purpose of obtaining gravel and sand.

An interesting phase of the drift is the brown to lead-colored clay which is seen resting above the Riverside sands already described. This is not in any sense a typical drift clay, and yet beneath it, and occasionally in it, are found boulders and northern gravel. It is very plastic, and may prove to be valuable in the manufacture of certain grades of clay goods.

Loess.—The most striking and picturesque feature of the topography of this region is the loess landscape. All along the Missouri, and a considerable distance up the minor streams, the loess is prominent. The earlier writers on this region referred to it as the "Bluff deposit," since it formed so prominent a feature in the river bluffs. At Sioux City it is 100 to

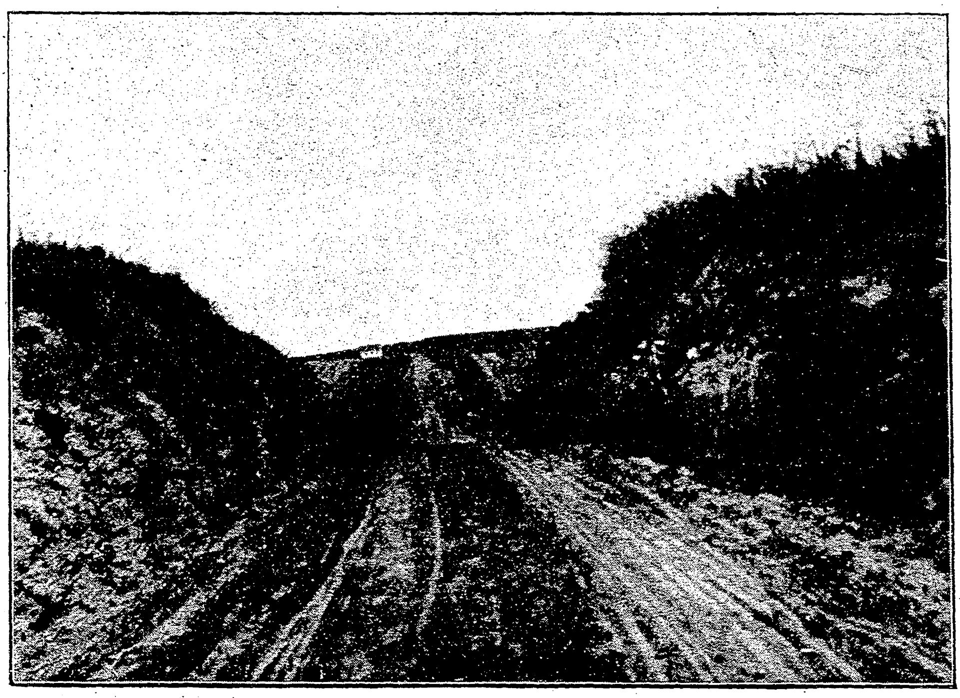


Fig. 40. Country wagon road in the loess region.

150 feet thick and is well exposed in the numerous street and railway cuttings as well as in natural sections. It is the typical, fine silt-like deposit of a light buff to ash-gray color, becoming slightly merged with the sand and drift below where the latter is present. It contains the usual loess-kindchen and is, in places, fossiliferous.

Concerning the origin of the loess some interesting evidence has recently come to light.* Near Riverside station there is an exposure, illustrated in figure 41 which shows an interbedding of till and loess. As exposed in 1894 the section here is as follows.

	FEET.
5. Loess of the usual character, thickening back on the hills to 100 feet or more, and in which Todd in 1889 collected *Helix hirsuta*, Lymnea and Cyclas	30
4. Clay, brownish to yellow, with numerous northern boulders irregularly disseminated in it; dividing toward the south and feathering out toward the north	2 to 12
3. Loess, ashen, silt-like, containing Succinia and other living forms	2 to 6
2. Gravel, very coarse, with northern boulders	10
1. Talus of loess	12

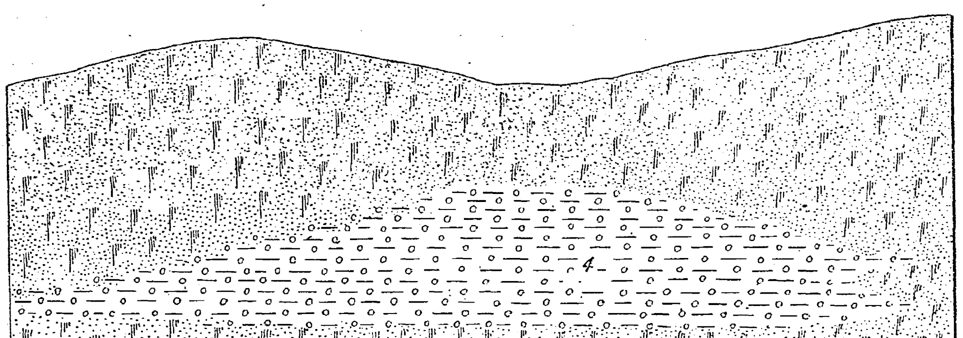


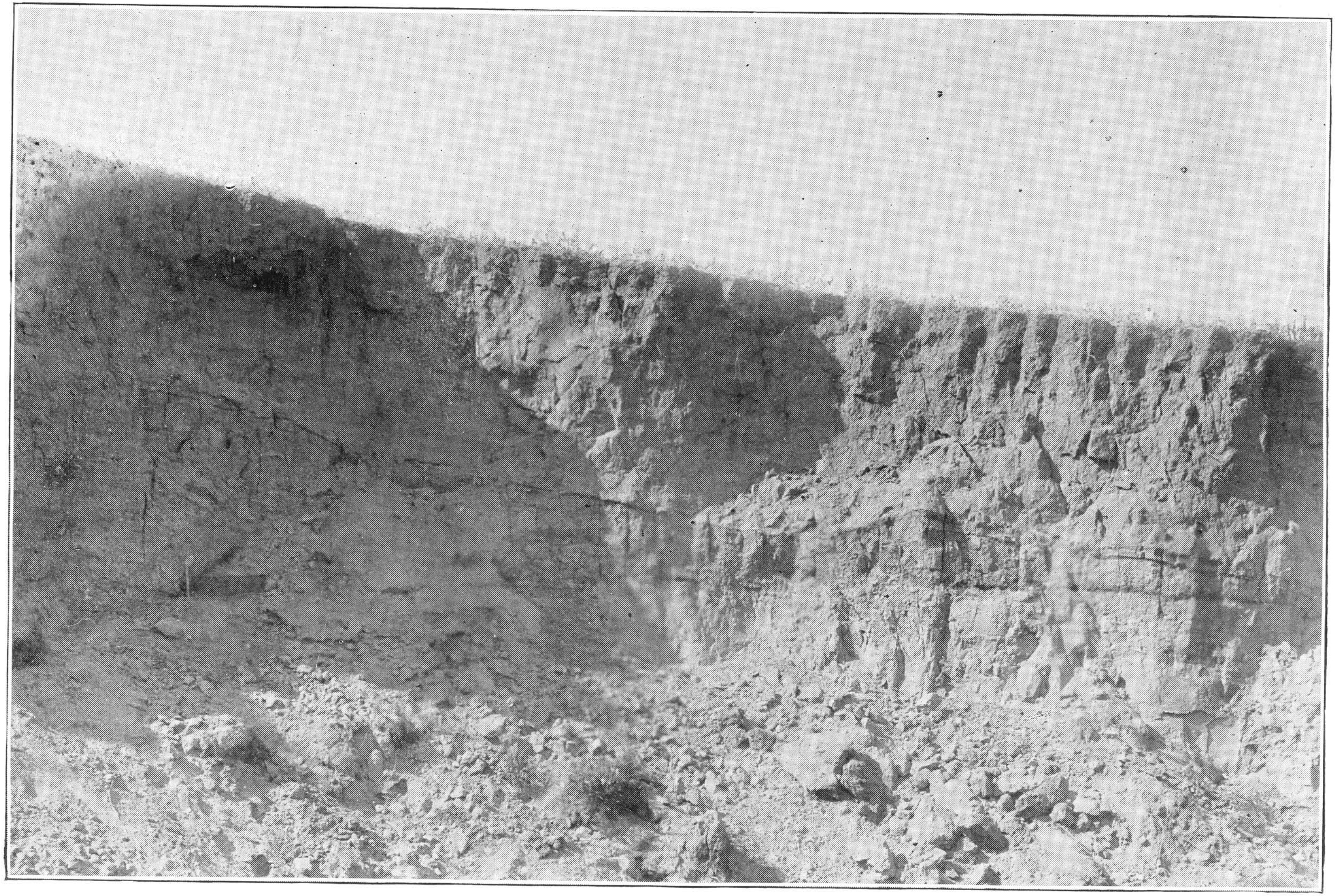
FIG 41. Drift interbedded with loess. Riverside, Sioux City.

For this exposure the explanation has been offered of a slipping of till and loess from higher levels down into a lower terrace of loess. There is, however, in one of the sandpits already mentioned, northeast of the Brugier bridge, a similar exposure which it does not seem can be explained in this way. This exposure, which is illustrated in plate v, is about 150 feet above the river, and the till is above any similar deposit

*See Proc. Iowa Acad. Sci., II, 20-23. 1895.

known to occur in the vicinity. The exposure shows a bed of typical till consisting of a matrix of dark brown clay, in which are numerous boulders of Sioux quartzite (one of these is pointed out by the hammer) and other northern rocks, with loess of the usual character, both above and below. The bed is of variable thickness, being at the center more than six feet and tapering from that to a feather edge. From the outline shown, the bed seems to be lens-shaped, with a considerable areal extent in proportion to its thickness. The loess is exposed to a considerable thickness, both above and below the till, and is in every way similar to the loess found in the neighboring cuttings.

The presence of the till in the loess indicates the contemporaneous origin of the two deposits, and it seems clear that in this case the explanation offered for the Riverside exposure can not suffice, even if in that it be deemed sufficient. The till here was probably dropped from a floating iceberg, while the loess itself was being deposited as a fine silt in the quiet waters of the expanded Missouri. The position of the various moraines renders it very probable that this took place at about the time the ice occupied the Altamont moraine. At that time the channel of the Missouri, it is believed, had already been cut. The valley was, in fact, even wider than at present. When the ice stood over the region northeast of Woodbury, this county was under water. The water was deep enough to float small icebergs over the tops of the pre-existing bluffs, and in the quiet depth of this body of water the loess was laid down as finer silts are now laid down over a flood plain. The tendency would be to disguise the roughness of any pre-existing topography, and hence the loess would be banked up against any old shore. It is known that the loess as a distinctive bed extends up the Maple to Danbury, and up the Little Sioux about to Oto. Beyond these points and over the upland it is not so typical and forms the covering which is the characteristic top dressing over the prairies of the northwestern counties.



TILL INTERBEDDED WITH LOESS. SAND PITS, NORTH RIVERSIDE, SIOUX CITY.

Terraces.—Since the deposition of the loess two important series of beds have been laid down. These are the river terraces and the alluvial deposits. Strictly they form but one series, since the modern flood plain of the river is merely the most recent terrace. Since, however, the earlier terraces were probably more or less directly connected with the later ice sheet, they may be considered as probably belonging to glacial history. The present flood plain must be considered as entirely postglacial.

Todd in his work on the Missouri river has found that several terraces may be traced. One of these, which may be called the loess terrace, is well shown south of Sioux City and at other points in the county. From various stations on the elevated railway, if one will look south toward Thompson's Bluff and the hills back of it and farther from the river, the terrace form may be readily seen. Thompson's Bluff runs out as a spit from the river bluffs which rise back of it. From a distance the upper surface of the lower bluff forms a distinct line in the landscape and is readily seen to be considerably lower than the hills farther east. Traces of this terrace may be observed at various points along the Missouri near Riverside. Todd has suggested that this terrace is a later silt deposition laid down at a time when the Missouri, while much higher and larger than at present, did not reach the height of the waters which laid down the older and more prominent loess.

Well-marked terraces are also seen along the minor streams in the county. Near Rodney on the Little Sioux there are three, as follows.

3. Older loess terrace, 210 feet above the river.
2. Newer loess terrace, 70 feet above the river.
1. Modern flood plain, 15 feet above the river.

Near Anthon the following occur:

3. Drift with thin top dressing of loess, about 150 feet above the river
2. Gravel terrace, well-marked, 1 to 1½ miles wide, 30 feet above the river.
1. Modern flood plain, 14 feet above the river.

These various terraces have not yet been correlated, and no certain inferences as to their relations and age may yet be drawn.

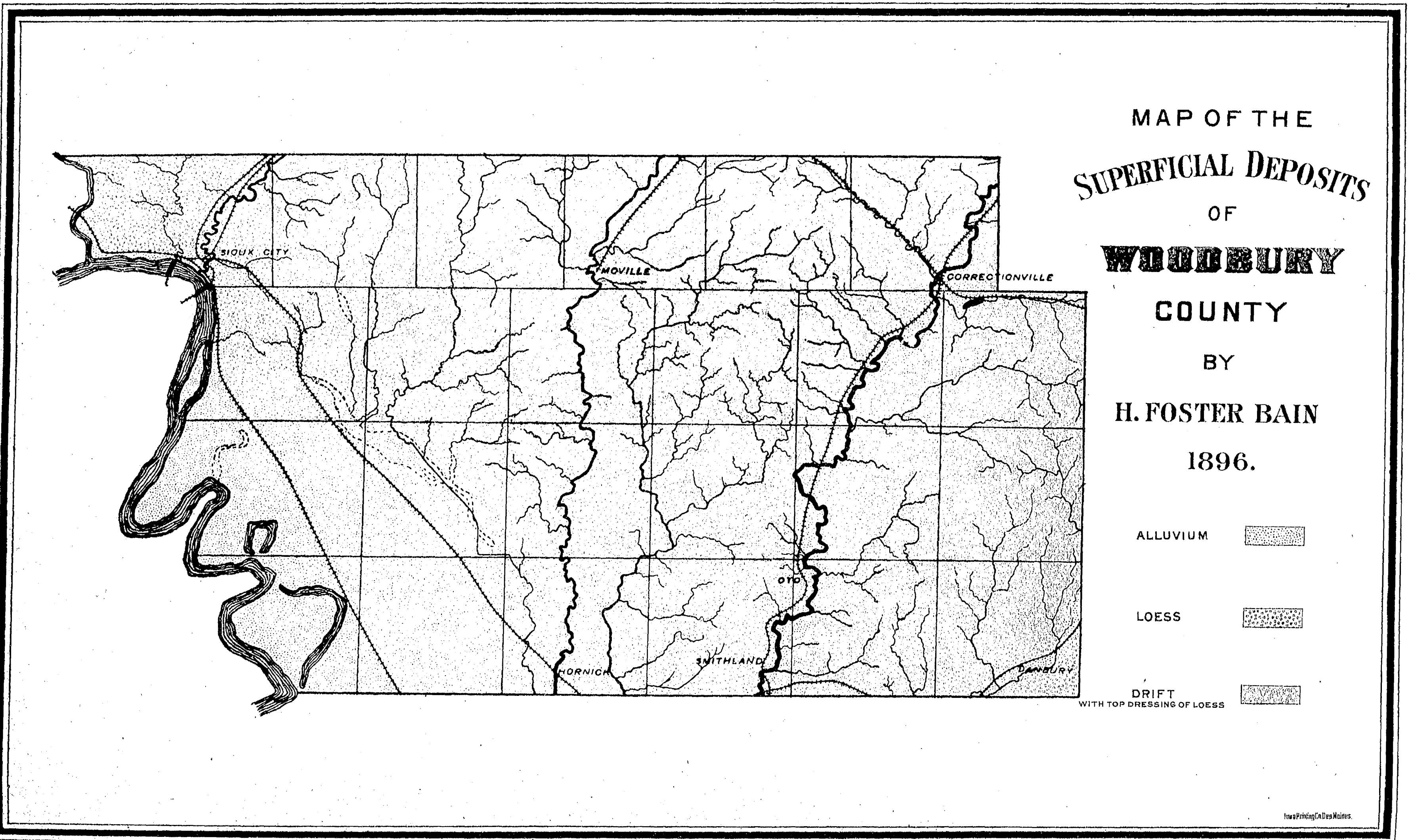
The structure of the terraces has not been investigated. It seems probable that they are genetically connected with the glacial deposits and were made at the time the Altamont moraine was formed. In the region there are terraces of deposition, a very good example being shown in Woodwarth's glen. Whether all the terraces had a similar origin, or whether they are, in part, terraces of erosion, can not be stated.

POSTGLACIAL DEPOSITS.

Alluvium.—On the accompanying sketch map the alluvium and other superficial deposits are laid down. The map is approximate only, but the delimitation of the major areas of alluvium is believed to be accurate. The character of the alluvium in nowise differs from that which is usually found in river bottom land. The great width of the Missouri flood plain, however, and its uniform surface make its artificial drainage a very difficult problem. Along the foot of the bluffs the usual back water swamp has developed in accordance with the well known law that flood plains rise toward the stream. In this swamp the small streams from the hills formerly lost themselves, but now the whole is drained into the Little Sioux by an artificial ditch.

Geological Structure.

General Structure.—The rocks of Woodbury county show but slight disturbances, and with the exception of the break between the Cretaceous and Pleistocene, they present a continuous sequence. The Dakota, Benton, and Niobrara follow each other in regular order, though it seems probable that within the county the Benton wedges out toward the south and east and the Niobrara overlaps, resting directly on the Dakota. The rocks seem to have been but little disturbed since deposition. A general section up the Sioux river and a


MAP OF THE
SUPERFICIAL DEPOSITS
OF
WOODBURY
COUNTY
BY
H. FOSTER BAIN
1896.
ALLUVIUM
LOESS
DRIFT
WITH TOP DRESSING OF LOESS
SIOUX CITY
MOVILLE
CORRECTIONVILLE
OTO
SMITHLAND
HORNICK
DANBURY

corresponding reconnoissance up the Missouri show that there is a slight dip to the north and west, but so far as this immediate region is concerned the dip might well be believed to be the original seaward inclination of the ocean floor. No folds or faults in the strata appear, and the occasional anticlines and synclines are of very inconsiderable extent.

Cross-sections. — A section along the Missouri and Big Sioux river from Sargent's Bluff to Cedar Bluff is shown in the accompanying figure. Good exposures for extending the section south does not occur, though the presence of heavy sandstone beds belonging to the Dakota, and of chalk beds of the Niobrara, is readily determined. In figure 42 the numbers refer to localities as follows: (1) Sargent's Bluff; (2) Floyd river; (3) Prospect Hill; (4) Riverside; (5) Cedar Bluff. The letters refer to the beds corresponding to those of the general section already given. The Dakota includes *a–g*, the Benton *h–i*, while *j* and *k* represent the Niobrara and loess.

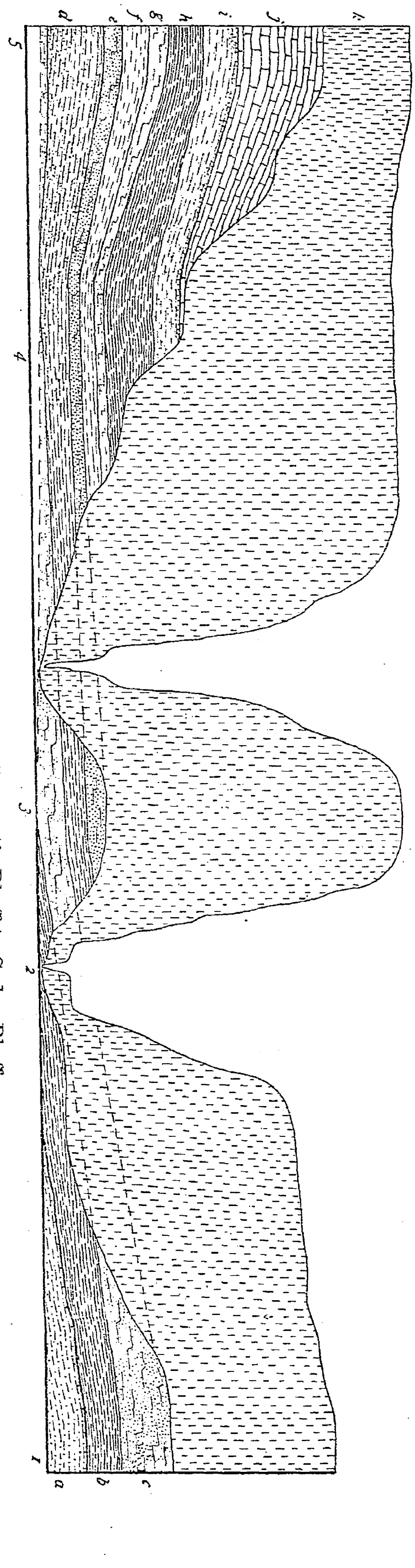


Fig. 42. Geological section from Sargent's Bluff to Cedar Bluff.

ECONOMIC PRODUCTS.

CLAYS.

CHARACTER AND DISTRIBUTION.

The geological formations exposed within this county are all clay producers or are capable of becoming such. The bedded rocks belong to the Cretaceous, and their general character may be inferred from the descriptions already given. Above the Cretaceous is the thin bed of sand which seems to be earlier than the drift. Over the drift there is, in the southwestern part of the county, a very heavy covering of loess in its typical form. Towards the northeast the loess covering becomes thinner.

A generalized section of the rocks of the county has already been given. Clay suitable for manufacturing purposes is obtained from numbers 1, 2, 5, 8, 10 and 15. Other layers might also be readily used.

The lowest clay beds worked in the county belong to numbers 1 and 2 and are exposed at Sargent's Bluff. These clay beds belong to the Dakota formation and are of excellent quality. The same formation includes the clay bed exposed at the foot of Prospect Hill and the clays penetrated in the prospecting at the North Riverside pottery. Both Dakota and Benton clays are taken from the pit of the Sioux Paving Brick company, the Benton clays being found above the soft white sandstone, here rather a sandy shale, which occurs some sixteen feet above the base of the pit. The clay below the base of the pit, exposed in a tunnel near the factory, is evidently to be correlated with that seen at the foot of Prospect Hill, and is above the Sargent's Bluff clay beds.

The Benton, or lower division of the Colorado, is best exposed at Cedar Bluff. As seen here it is made up of two separate clay beds of nearly equal thickness. The lower bed is more argillaceous and represents the horizon now worked at Riverside. The upper bed is rarely so pure as the lower. It frequently merges at the top into the chalk and limestone of the Niobrara. There are thus four well marked clay horizons in the Cretaceous of the county, three being in the Dakota and one in the Benton. They afford a wide variety of material and are adapted to almost any kind of clay work. Drain tile, sewer pipe, stock, face, enamel and paving brick, terra cotta and pottery may all be manufactured, and most of them are now actually being made, from the Cretaceous clays of this region. It is, perhaps, significant that the great clay industries of New Jersey and Maryland are founded upon beds of the same age.

In addition to the abundance and great variety of Cretaceous clays present in Woodbury county, there are other valuable deposits. The thin bed of blue-gray clay which overlies the Cretaceous near Sioux City is quite plastic and free from impurities. Apparently it would be valuable, and might be readily used.

The drift in this county is thin and of irregular distribution. It seems hardly likely that it will ever rank as an important clay producer. Above it is the loess, which occurs in remarkable purity and in great thickness. With the exception of the lime concretions which are often found in it, it contains nothing deleterious. The percentage of iron present causes it to burn to a good red color, and the ease with which it is obtained and manipulated leads to its large use. It is a material capable of making most excellent ware, and is widely used.

Woodbury county is exceptional in the large amount of alluvial land which it contains. Fully one-fourth of the area of the county is covered by material of this character. Alluvial clay is so readily made up into common brick and drain tile, by the simplest and least expensive processes, that in other regions it is largely used. Here, however, the exceptional abundance of better clays make it hardly probable that the alluvium will ever meet with much favor.

CLAY INDUSTRIES.

The works of the Sioux Paving Brick company, of which Mr. W. B. Lower is manager, are located between Riverside and North Riverside at Sioux City. The plant was established some seven years ago and has since been extensively enlarged. A Penfield plunger was at first used, but a Chambers machine with a rotary cut-off has since been substituted. The Chambers machine has given excellent satisfaction. A Penfield steam re-press has also been used to some extent.

The brick are dried in part in steam heated sheds, and in part under ordinary roofed sheds. In burning, both a Hoffman ten-arch partition kiln, having a capacity of 400,000 brick, and a clamp kiln of 350,000 capacity are used. The material is taken from the Benton and Dakota horizons of the Cretaceous, and is dug from a pit near the kilns. A general view of the pit is shown in figure 43, and a detailed section of the strata is given below.

		FEET.	INCHES.
13.	Loess (on slope)	10	
12.	Shale, very arenaceous, with selenite in veins	14	
11.	Shale, light to drab gray, in part sandy; selenite in seams	15	
10.	Shale, with impure limestone in irregular boulder-like masses	3	
9.	Shale and sand, ferruginous, in alternating layers	4	
8.	Shale, gray, non-siliceous	10	
7.	Shale, grayish to drab, with four-inch rock ledges about the center	6	
6.	Sandstone, calcareous, in part shaly	4	
5.	Shale, gray fissile	2	6
4.	Shale, gray, very finely siliceous, with ferruginous masses near middle, also in upper part	5	6
3.	Shale, lignitic		8
2.	Sandstone, light-colored	7	
1.	Shale	1	

Number 12 is rather impure, containing in addition to the gypsum mentioned, a thin ledge of hard, calcareous sandrock, The shale of number 4 is of good quality though rather refractory. Number 8 contains the Benton fossils already mentioned.

Nearly all the material taken from the pit may be used. Ordinarily the strata from number 3 to number 12, inclusive, are after the gross rock impurities have been sorted out,

FIG. 43. Clay pit of the Sioux Paving Brick Co., North Riverside, Sioux City.

mixed with a nearly equal proportion of loess and soil material.

The brick shipped from this plant are of excellent quality and find ready sale throughout northwestern Iowa and neighboring portions of the adjacent states.

The plant of the Northwestern Sewer Pipe & Tile company is located a short distance south of the Sioux Paving Brick works. The material used is obtained from the Cretaceous, the clay being taken from beds 4 and 7 of the following section.

	FEET.
7. Shale, gray to white, siliceous	15
6. Lignite, impure	1

		FEET.
5.	Sandstone, marly, white	$2\frac{1}{2}$
4.	Shale, gray to white, with ferruginous colorings; also layers of siliceous boulders	12
3.	Shale, drab to white, arenaceous	2
2.	Sandstone, white to red	7
1.	Shale, gray, sandy, especially below; exposed	7

The clay is treated both by the dry-pan and the wet-pan process and is worked upon a Vaugh machine. The ware is dried in a large two story steam heated dry shed, and burned in Eudaly kilns, of which there are nine on the premises. The pipe are glazed with salt, and have a decided metallic ring as well as a handsome appearance. A considerable variety of sizes is turned out. Sewer pipe ranging in diameter from three inches to two feet are being shipped. The early attempts at the manufacture of sewer pipe at this plant were quite discouraging, but under new management better results have been obtained.

The Sioux City pottery is located north of the Sioux Paving Brick works; it was established some years since by Mr. J. K. Prugh, but has not been in operation recently. The clay used was taken from a bed corresponding to number 1 of the section at the Sioux Paving Brick works and seems well adapted for use in the manufacture of ordinary pottery. When the plant was in operation a considerable portion of the ware was crimped. This could probably be avoided by proper treatment.

The Sioux City Brick & Tile Co., operate a large plant at Springdale, a suburb of Sioux City. They have a large annual output of building brick and command an excellent trade. The material used is the loess, and is taken from the bluffs along the Floyd river. It is for the most part quite pure, though lime concretions are abundant in certain portions of the pit. The clay is moulded on a Kells & Son stiff-mud machine, and a small portion of the output is treated on a Drake re-press. In drying steam heat is used. A large Radford partition, and a Hoffman continuous kiln are used in burning.

The Peterson & Smith brick yard is in the valley of Prairie creek, at Hamilton and Twenty-fourth streets. The loess is used, being moulded on an H. Martin soft-mud machine, dried in the open air and burned in clamp kilns.

C. B. Woodley operates a brick yard at the foot of Orchard Hill, near the Illinois Central railroad. A Wallace machine was formerly used, but a Kells & Sons has been substituted. The loess is taken from a slope near the plant, and makes up into a smooth brick of excellent color.

The Sargent's Bluff pottery was founded in 1838, being located at first on the west side of the Missouri river. In 1862 it was transferred to its present site. Mr. E. Mattox now runs the plant, which consists of the ordinary pug mill, jolly and turning-wheel. A small down draft kiln is used in burning. The clay used is from a bed corresponding to No. 2 of the section at the Holman pit. The bed is seven feet thick and seems well adapted to the manufacture of ordinary pottery. It stands a high heat and takes a good glaze. The output of the yard is small.

The C. J. Holman & Bros. Brick and Tile works were founded in 1867. For the first two years hand-made brick alone were made. Later a Van Vallen horse power mud mill was used, but in 1880 a Cream City stiff-mud machine was substituted. This was in turn replaced in 1887 by a Penfield machine, and in 1890 a Chambers was set up. A number of different crushers, including the Wallace, Penfield, Potts and a Frey-Sheckler dry-pan. The latter is now used. The plant also includes a steam power Raymond re-press, ample shed room for drying, six down draft kilns with a total capacity of 400,000 brick, and one clamp kiln holding 225,000 brick.

The output is large and includes common, structural and fire brick, pavers, sidewalk blocks and bricks, and stock brick from the re-press.

The clay used is from the Dakota horizon, and is dug from the south side of the long spit of high land known as Sargent's Bluff.

The general section at this point has already been given. The details seen at this individual pit are as follows.

		FEET.
7.	Loess, typical on slope	40
6.	Sandstone, exposed	10
5.	Shale, lignitic to argillaceous	1¼
4.	Shale, argillaceous to sandy	5
3.	Shale, unctuous, dark to light gray in color	8
2.	Shale, "white," somewhat arenaceous	6
1.	Shale, buff to yellow and gray	16

With the exception of the sandstone and the lignite, the entire section is workable. The loess may be used for various grades of structural brick. Number 4 is used for quite a wide variety of purposes. Number 3 is well adapted to the manufacture of pottery, burning white with very little shrinkage. Number 2 is properly a fire clay, but combines readily with the less refractory clays and is largely used in the manufacture of common brick. Number 1 is especially good for dry-press building brick and pavers. It contains concretions of ferruginous sandstone, in which, as well as in the clay itself, the plant remains already noted occur.

The entire plant is conveniently arranged and it has ample railway facilities, being connected with the Sioux City & Pacific railway, which runs just west of the yard. The output of the plant is of excellent character and commands a ready market. So far but few paving brick have been manufactured, though a number of the streets of Sioux City have been paved with brick made at this plant.

The Sargent's Bluff & Sioux City Brick company operate a plant located near that of Holman Bros. Up to 1892, when the plant was destroyed by fire, the company was known as the Terra Cotta Tile and Brick company. Early in 1893 the plant was entirely rebuilt. It now includes a Boyd dry-press and dry-pan, a Drake crusher, a large storage dry-house with elevators, a Barnhart steam shovel, five Eudaly kilns having a combined capacity of 1,200,000 brick, and a Radford continuous, fourteen-compartment kiln having a capacity of 324,000 brick.

The clay used comes from the Dakota formation, and is taken from layers essentially similar to those exposed in the Holman pit. The principal output of the plant is front brick, and numerous beautiful soft tints, ranging from a deep red to cream white, are produced. Veneerings are being experimented with, with good prospects for success. The quality of the ware produced is excellent and the output large. While a considerable portion of the product goes to Sioux City, a large number of brick are shipped to various other markets.

CEMENT.

The manufacture of Portland cement is a business which in this country is rapidly expanding. The Western Portland Cement company of Yankton has shown that the chalks and clays of the upper Missouri region are especially well adapted to this use. At the Yankton plant the chalk of the Niobrara and the clay of the Pierre are used, and by the wet process are made into an excellent grade of cement. The material as it comes from the pits is ground and mixed together in proportions determined by analysis. This "slurry" is dried under sheds and then broken up and burned. The burned material is reground by means of rolls and millstones and is then ready for the market.

Sometime since, experiments were carried on in Sioux City, in the course of which it was demonstrated that excellent cement could be made from material occurring at that place. The proportions used were five parts of one clay, two of another, and one of chalk.* These materials all occur in abundance along the Big Sioux, north of Sioux City, and there seems to be no good reason why the manufacture of cement at some point along the river, if carefully carried on, would not be successful. The value and importance of a good cement, in connection with the clays, which must always furnish the chief building material of the region, is apparent. The presence also of rock well adapted to concrete work

*Lonsdale: Proc. Iowa Acad, Sci., II, 173. Des Moines, 1895.

though not so readily available for dimension stone makes possible a wide use of cement independent of brick construction.

BUILDING STONES.

The rocks of the county do not afford any very great supply of stone suitable for building. Some portions of the Dakota sandstone may be available, especially the quartzitic facies, such as is seen at the Reese quarry; but the supply of such material is very inconsiderable. Certain parts of the Niobrara chalks and limestones have been quarried to a limited extent in this region. The chalk rock, while soft, stands on the whole better than could be expected, but its use can not be recommended. So far as relates to supplies of building material, the clays must always be the main dependence of the people of this region.

LIME.

The Niobrara chalks and limestone beds were in the early days burned for lime and afforded a fairly good article. The local product has been, however, long since driven from the market by the better grades of eastern lime, and it seems doubtful if the industry will ever be revived to any great extent.

SAND AND GRAVEL.

These materials may be found along the major streams. The pits north of Sioux City have already been described. Along the Little Sioux the middle terrace furnishes in places good material of both kinds. The two materials are, however, so intermingled that neither can be used without screening. The loess, while not of much value for ballast, is much used for roadmaking; being admirable for fills and roadbeds.

COAL AND LIGNITE.

There is no reason to believe that coal in paying quantities will ever be found within the limits of the county. If the coal measures ever extended over the region, they must have been very largely, if not entirely, removed during the long succeeding period of erosion. Such limited areas as may possibly remain, are securely buried below 300 to 500 feet of overlaying Cretaceous and drift. When one remembers that in the coal region of Iowa the beds themselves are so irregular that in some cases as many as ten or more diamond drill holes must be bored in a single section before the coal bed is outlined definitely enough to warrant planning the mine workings, it will readily be seen that the expense of prospecting would here always exceed the returns reasonably to be expected, even admitting the possible presence of outliers of coal; a point which is itself open to more than doubt.

The Cretaceous beds contain, as has been said, certain bands of lignite. These usually occur in the Dakota, though the bed so long intermittently worked at Ponca is found near the base of the Benton. Thin beds may be noted at several points along the Missouri and Big Sioux, but those seen in this county are of very inconsiderable thickness. These lignites are impure forms of coal. As shown here they usually consist of thin streaks or seams of coaly matter, from one-fourth to three inches in thickness, interbedded with loose carbonaceous clay. The latter is often plastic and may be moulded with the fingers. The thinner streaks of coaly matter burn readily, but the proportion of combustible matter to clay and dirt is very small, and they apparently can not be made available except by washing the dirt out. If a bed of sufficient thickness to justify the expense should ever be found, it is possible that, by grinding and washing, a material could be obtained which in the form of briquetts would find ready sale as a fuel. Such seams are not, however, known to occur. The Dakota, as exposed along the river, shows no coal beds approximating the requisite thickness, and there is no good reason to believe that the exposures here are other than typical.

WATER SUPPLY.

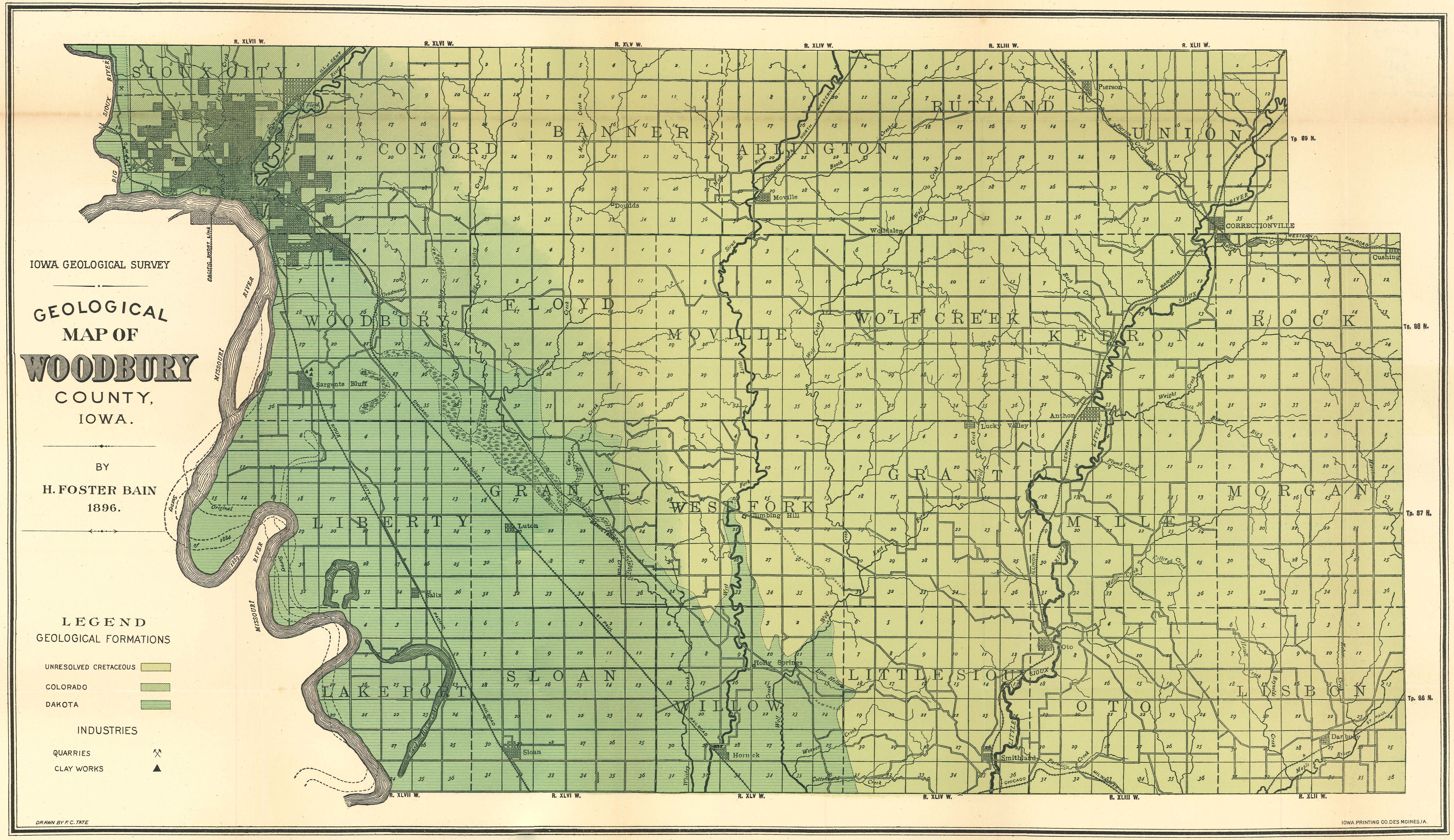
The many rivers and streams afford at all ordinary times abundant supplies of water. Wells of good character may almost always be obtained by sinking to the base of the loess. In Sioux City the wells derive their water from the drift. With the exception of those which are sunk in recently made land, they are not affected by the rise and fall of the river. The drift horizon is marked by a number of springs in various parts of the county. There is a second spring horizon at the base of the Niobrara. One of the best known springs which belongs to this horizon is the Lithia spring on the Talbot farm (Tp. 89 N., R. XLVIII W., Sec. 1).

Water was obtained in the deep well at Sioux City at three horizons. A water-bearing sand and limestone was encountered at 540 feet, and extended to 570 feet. From this horizon water rose to within twelve feet of the surface. At about 1,250 feet a second water-bearing sand rock was encountered. This extended to 1,270 feet, and a flow of three gallons per minute was obtained. At 1,480 feet a third flow was obtained.

The water from these horizons seems to come from the Paleozoic, and hence to be below the Cretaceous. The Dakota sandstone, which forms the great source of phreatic water throughout South Dakota, crops out along the Sioux and Missouri rivers. It is marked on the Nebraska side of the Missouri by a number of beautiful springs, and apparently loses its water supply, to a very large extent at least, before entering Iowa. There is very little reason for looking upon it as a probable source of water supply in this state.

SOILS.

The soils of Woodbury county are of great fertility and value. They are made up of alluvium and loess, and the absence of boulders makes cultivation easy. The porous nature of the loess covering of the upland simplifies the problem of drainage.


IOWA GEOLOGICAL SURVEY
GEOLOGICAL MAP OF WOODBURY COUNTY, IOWA.
BY
H. FOSTER BAIN
1896.
LEGEND
GEOLOGICAL FORMATIONS
UNRESOLVED CRETACEOUS
COLORADO
DAKOTA
INDUSTRIES
QUARRIES
CLAY WORKS
R. XLVII W.
R. XLVI W.
R. XLV W.
R. XLIV W.
R. XLIII W.
R. XLII W.
Tp. 89 N.
Tp. 88 N.
Tp. 87 N.
Tp. 86 N.
SIOUX CITY
CONCORD
BANNER
ARLINGTON
RUTLAND
UNION
WOODBURY
FLOYD
MOVILLE
WOLF CREEK
KEDRON
ROCK
LIBERTY
GRANGE
WEST FORK
GRANT
MILLER
MORGAN
LAKEPORT
SLOAN
WILLOW
LITTLE SIOUX
OTO
LISBON
Pierson
Moville
Correctionville
Cushing
Sargents Bluff
Luton
Salix
Sloan
Hornick
Climbing Hill
Lucky Valley
Anthon
Oto
Smithland
Danbury
Doulds
Wolfdale
MISSOURI RIVER
BIG SIOUX RIVER
LITTLE SIOUX RIVER
DRAWN BY F.C. TATE
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* Hist Woodbury and Plymouth counties, Chapter II, Topography and Geology, pp. 14-46 Chicago, 1890-1891,