GEOLOGY OF PLYMOUTH COUNTY

BY

H. F. BAIN.

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CONTENTS.

INTRODUCTION.

Plymouth county lies on the western border of the state and is the third south of Minnesota, Sioux and Lyon counties intervening. To the east is Cherokee county and to the south is Woodbury. On the west it is separated by the Big Sioux river from Union county, South Dakota. The western boundary of the county, being formed by the river is an irregular north-south line. The remaining boundaries are simple land lines. The area extends twenty-four miles from north to south and from thirty-four to forty-one miles east and west. It includes townships 90 to 93 north and portions of ranges 43 to 49 west. The total area is 860 square miles or 490,400 acres.

To the fact that the county nowhere touches the Missouri river, the great highway of early commerce, is due the further fact that the exposures within its limits were not much studied by the various geologists who in earlier years visited Sioux City and contributed to our knowledge of Woodbury county.* The exposures along the Sioux as far north as the mouth of Broken Kettle were probably visited by several of these earlier explorers, but our knowledge of the geology of the county begins with the visit made to it by White and St. John.† Subsequently Todd published notes on the geology of the region‡ and has more recently published two valuable papers covering adjacent portions of South Dakota.** Soon after the organization of the present Survey the county was visited by Prof. Calvin and certain preliminary results have been published.§ Later a section along the Big Sioux was made by the present writer,‖ and the neighboring county to the southward was reported on in detail.†† In the course of this preliminary

*See Geology of Woodbury county, Iowa Geol. Surv., vol. V, pp. 265-et seq. 1896.

†Geol. Iowa (White), 1870, pp. 229-232.

§Proc. Iowa Acad. Sci., vol. I, pt. iii, pp. 13-16. 1893.

**South Dakota Geol. Surv. Bul. No. 1; Bul. U. S. Geol. Surv., No. 144.

‡Iowa Geol. Surv., vol. I, pp. 145-161. 1893; Ibid, vol. III, pp. 210-236 1895; Proc. Iowa Acad. Sci., vol. I, pt. iii, pp. 7-12. 1893; Amer. Geol., vol. XI, pp. 300-307. 1893; vol. XIV, pp. 140-161. 1894; Proc. Amer. As Adv. Sci., vol. XVIII. 1894.

‖Iowa Geol. Surv., vol. III, pp. 98-114. 1895.

††Geology of Woodbury county, Iowa Geol. Surv., vol. V, pp. 241-299. 1896.

work and some later excursions through portions of the county a number of notes were accumulated and within the last summer some weeks were spent in a further study of the area as a whole; the present report being the result.

In the earlier work of the present Survey, as well as in that of its predecessors, the problems of the drift and surface formations were dealt with but cursorily. The immediate interest was centered in the indurated rocks. In the work of the past field season it was the drift which was especially studied. The present is a report on the first area studied by the Survey with especial reference to the drift problems of northwestern Iowa. As such it necessarily is incomplete. Certain generalizations which present knowledge indicates to be correct may, when the neighboring areas are studied, need modification. Many points must remain unsettled and many phenomena, for the present, unexplained. It has been thought better in writing the present paper to adopt as a working hypothesis that which seems at present most probably correct; the points of doubt being indicated from time to time in the discussion. It is hoped that in this way doubtful points may not be too much neglected and yet a useful report be made.

PHYSIOGRAPHY.

TOPOGRAPHY.

The area under discussion lies on the western or Missouri side of the great watershed which divides Iowa into two unequal portions. Its streams flow into the Missouri, directly or through tributary drainage. Its surface as a whole slopes to that great waterway. The county forms a partially dissected plain with the main towns located in the valleys.

The elevation of the more important points in the county is shown in the following table, prepared from railway levels. Since the development of the drainage has been controlled by the Missouri at Sioux City the elevation of the flood plain and of low water at that point is given for comparison.

STATION.	FEET.	AUTHORITY.
Akron	1,155	C., M. & St. P. Ry.
Chatsworth	1,152	C., M. & St. P. Ry.
Dalton	1,212	S. C. & N. Ry.
James	1,120	I. C. Ry.
Kingsley	1,241	C & N. W. Ry.
Le Mars	1,224	I. C. Ry.
Merrill	1,167	I. C. Ry.
Oyens	1,263	I. C. Ry.
Remsen	1,314	I. C. Ry.
Seney	1,223	C., M., St. P. & O. Ry.
Struble	1,271	S. C. & N. Ry.
Westfield	1,131	C., M. & St. P. Ry.
Sioux City (railway station)	1,104	C., M. & St. P. Ry.
Low water	1,076	Mo. Riv. Com.

Taking the elevation of a series of towns from east to west a general slope toward the west is indicated.

	FEET.
Remsen	1,314
Oyens	1,263
Le Mars	1,224
Dalton	1,212
Akron	1,155

Compare also Struble, 1,271, and Chatsworth, 1,152; Merrill, 1,167, and Westfield, 1,131; Kingsley, 1,241, and James, 1,120. Such comparisons are confessedly inaccurate, since the various towns do not bear equivalent relations to streamways and valleys. They, however, indicate at least approximately the true relations as may be seen by a comparison of upland surfaces, calculated from barometer readings tied to railway levels.

	FEET.
Highland near Remsen	1,404
Le Mars	1,334
Dalton	1,312
Akron	1,275

This comparison, however, neglects the divide between the Floyd and the Big Sioux which was found in Preston township by barometer readings to be approximately 300 feet above Chatsworth.

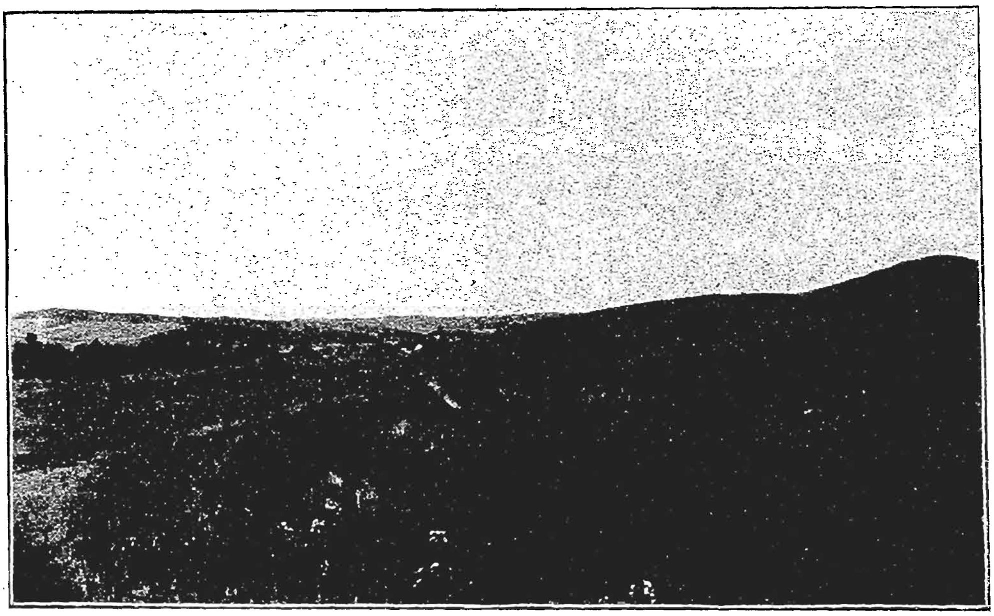


FIG. 1. Loess slopes along Broken Kettle creek, immediately above the "shut in" at Milleneryville.

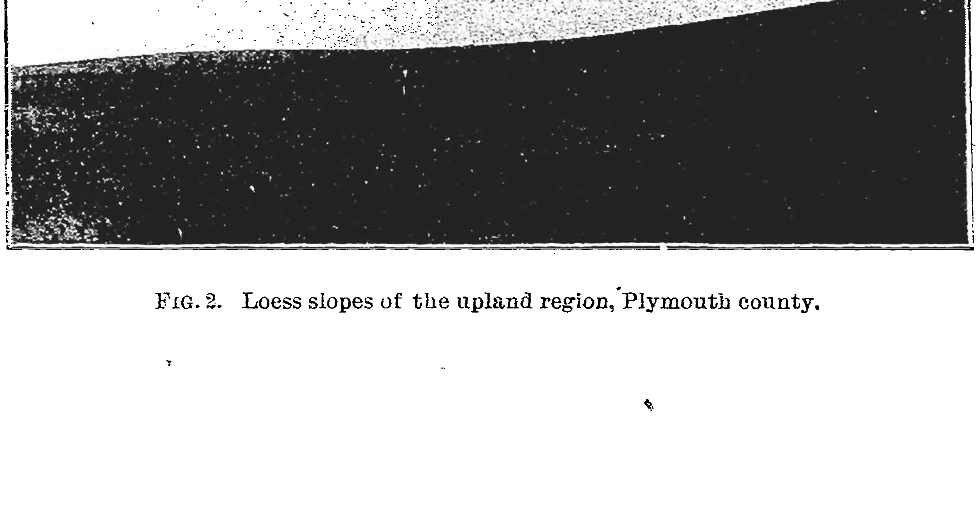


FIG. 2. Loess slopes of the upland region, Plymouth county.

The slope to the south may be readily seen by following any given line in that direction. For example, Chatsworth, 1,152, Westfield, 1,131, Struble, 1,271, Dalton, 1,212, Merrill, 1,167, James, 1,120, Remsen, 1,314, Kingsley, 1,241. The last comparison is the most significant, since it is between two points located upon different water courses. Chatsworth and Westfield are both in the valley of the Big Sioux; Struble and Dalton, Merrill and James lie in the Floyd valley. The base level of erosion in these two valleys is in each case controlled by low water mark at Sioux City, 1,076. Remsen, however, lies in the valley of Deep creek, a tributary of the Floyd, while Kingsley is in the valley of the west fork of Little Sioux.

In general these elevations indicate an upland, lying at an elevation of about 1,400 feet, with a series of river valleys cut from 100 to 300 feet below it. The depth of most of these valleys is controlled by low water mark at Sioux City and is proportional at any point to the area drained by the stream above that point and to the distance from Sioux City. Along any stream the altitude increases with the distance (compare Merrill, Dalton, Struble), while with the same distance the altitude is inversely proportional to the size of the stream, or dependent upon the area of the valley above (compare Struble and Chatsworth).

Topographically Plymouth county is divisible into two rather sharply contrasted areas; the major occupying much the larger portion of the county and the minor being found in the southwestern part. Over the main portion of the county the topography shows characteristic erosion curves and surfaces. The land forms are manifestly the result of river and stream erosion and the general plain, which is so characteristic and striking a feature of the landscape, breaks up into a series of wide, shallow valleys. These digitate, and while in cross-section and general appearance they seem to be poorly developed, a close study shows that they really control the drainage of the county quite exactly. The land is all drained and upland sloughs are almost unknown. The valleys have long and gentle side-slopes, eighty feet per mile seeming to represent quite closely the average. Steeper slopes are only found at points of recent erosion. For example, along a small tributary of Clear creek, joining that stream near Kingsley (Secs. 24, 13 and 14, Elkhorn Tp.), the bluffs on the southwest side are quite abrupt and show slopes considerably steeper than are common in the region. Such phenomena are, however, due merely to local accidents of erosion. In general the slopes are long, gentle and unbroken. Wherever one looks he sees the same gentle rolling plain with a sky line which is almost, but not quite, even; a slightly sinuous or wavy line. The surface is uniformly covered with loess and while, as will be later shown, the latter is quite thin, perhaps not averaging more than six feet in thickness, there has been so little erosion since its deposition that it has been quite rarely cut through. One may drive forty miles or more in almost any direction and see nothing but loess and alluvium, and in the whole of the eastern portion of the county exposures of the sub-loessial beds are so rare that they may be counted upon the fingers.

The valleys in this region are well developed. They have flat, and often relatively wide, bottom lands. The amount of alluvium may be important. In the perfection of the drainage system and the development of the bottom lands the valleys seem to require that one should allow a considerable period for their development. There are, however, certain other facts which must be taken into account, but which are best discussed in connection with the drift. It is perhaps sufficient to say here that the erosion was manifestly accomplished before the deposition of the loess. Since that period there has been almost no erosion.

In the southwestern portion of the county there is a limited area which is topographically distinct from that just described. In a general way it may be defined as lying southwest of a line drawn from Westfield to James. In this area the predominant land forms are still those of erosion, but a very different type of erosion from that of the other parts of the county. The slopes are much steeper, and abrupt bluffs abound. Indeed the inter-stream areas stand up like peaks and spires, and the streams seem to wander between them where they may, rather than where they will. This region shows the characteristic and often described loess landscape with its bewildering complex of pointed, semi-detached hills, and winding, tortuous yard-wide divides. It marks young and vigorous erosion upon easily cut beds, which, though they can if need be, stand abrupt without grass covering, yet usually are beneath a surface of coarse prairie grass. The hills, with slopes often too steep for sod, hint to man of Nature's plan by developing a series of one-foot terraces, all but concealed below the grass. In this maze of hills, stream courses are erratic. One climbs a hill to get a synthetic view of the country and discovers instead but a larger and more complex maze of hills similar to that on which he stands. To the west is the broad bottom land of the Big Sioux and the Missouri, and out on the edge of the bottom land the hills push with frowning bluffs and steep slopes, which rise altogether 280 to 300 feet from the water. At the base are exposures of Cretaceous, and above these rocks, drift occasionally shows. Where the earlier formations are not actually exposed their presence is often indicated by the sharply moulded terrace of the Niobrara or scattered surface bowlders from the bowlder clay.

Along its inner border this topographic region is not always sharply defined. At points it fades away, shading off into the normal drift-plain erosion forms, losing its identity so gradually that one can not, save arbitrarily, put down a line to limit it. At other points the line is very sharp. For example, if one drives southeast from Westfield along the road which leads over the hills towards Millineryville, he will see spread out to the east the broad, open valleys and gently rounded slopes characteristic of the eastern portion of the county. To the west, and rising above this eastern upland plain, are the jumbled peaks and narrow, closed-in valleys of the loess region. Again, if one drives down Broken Kettle creek, he finds at first the smooth, gentle slopes and the wide, flat-bottomed valley of a drift-loess region. In section 23, of Tp. 91 N., R. XLVIII W., this valley closes in sharply. (Plate xxv.) The bluffs rise abruptly, gaining an additional height of nearly fifty feet, and the bottom land disappears. For a valley to take on such characteristics towards its mouth, rather than towards its source, is certainly anomalous. Its explanation seems to lie in the fact that the loess of the southwestern part of the county, as defined above, is later than that overlying most of the region; that it is a wind deposit and has been whipped up on the hills and poured down into these older valleys.

These two topographic regions, then, tell the story of an earlier period of river erosion and a later period in which the action of the wind was dominant.

DRAINAGE.

The streams of Plymouth county are all directly or indirectly tributary to the Missouri. Much the major portion of the area is drained by the Big Sioux and the Floyd with their various tributaries. The Big Sioux is the more important stream. It rises in South Dakota and for about seventy-five miles forms the western boundary of the state. Along Plymouth county it has a valley from one to three miles broad and with long gentle slopes rising 120 to 165 feet above the bottom land, the river itself cutting thirty-five feet into the latter and approximately 300 feet below the divide lying between it and the Floyd. The stream has a fall of about 1.4 feet per mile. Its tributary drainage is mainly from the east, the nearness of the moraine limiting it on the west. Its most important tributary within the county is Broken Kettle creek, which has its headwaters well to the northern line of the county and a course approximately parallel to the Big Sioux till the latter makes the bend to the southeastward at Westfield. The two streams meet in Hancock township within about five miles of the southwestern corner of the county. Indian creek, with its headwaters in part near Ireton in Sioux county, and in part near the headwaters of Broken Kettle, flows west to the Sioux near Chatsworth. It has a well developed valley cut, however, almost entirely in the drift. Between Indian and Broken Kettle creeks are a number of pretty little streams including Beaver, Westfield, French and Rock creeks, which divide the narrow territory between the Broken Kettle and the Sioux.

Between the Floyd and Broken Kettle is Perry creek, an important stream with a deep, though narrow, valley. The Floyd includes the east branch rising in Osceola county and receiving within Plymouth county Deep and Plymouth creeks, and the west branch or Beaver creek rising in Sioux county and receiving Mink creek from the west. These two branches unite near Merrill. In the southeastern portion of the county is the West Fork of Little Sioux, receiving Deer and Clear creeks. Between the Floyd and West Fork of Little Sioux are the upper branches of Elliott and Whisky creeks. The streams of the county seem to have had their origin in the glacial period. There is no known evidence that any of them are pre-glacial. It is quite possible that this portion of the Big Sioux antedated the coming of the ice but there is no sufficient evidence yet in hand proving that the stream is so old. It is certainly, however, older than the Wisconsin, since its valley is filled with a gravel train from that ice. The other streams of the county afford no such data for fixing their age. They are older than the loess and their valleys are cut in the drift. The relative breadth and shallowness of the valleys would seem to indicate that the process of their erosion was a slow one. There are other phenomena, however, which make it doubtful whether such an interpretation is allowable.

STRATIGRAPHY.

GENERAL RELATIONS OF STRATA.

In Plymouth, as in the remaining counties of Iowa outside the driftless region, there are two great classes of rocks. These are widely different in age and usually show considerable differences in character. In a broad way they may be spoken of as the consolidated and the unconsolidated formations, and yet a division on this basis does not always place the same things together. In general the two divisions are spoken of as the surface formations and the underlying rocks, but even this terminology is apt to lead to confusion; perhaps is more apt to do so here than elsewhere. In still more general and more popular speech the classes are distinguished by restricting to the one the term rock; the looser beds being spoken of as dirt, sand, clay, gravel, etc. This is the poorest classification of all since the state of aggregation does not control either the chemical or mineralogical constitution of the mass, and hence both classes of beds equally include rock. In the region under immediate consideration the underlying rocks include sandstones, clays, shales, chalk and limestone. The overlying series include deposits of alluvium, loess, gravel and bowlder clay or till. One group is composed of marine sediments, the other includes terrestrial deposits. The former belongs to the remote and the latter to the immediate past. The older series is known to the geologists as the Cretaceous; the younger the Pleistocene. That is, the one was formed at approximately the same time as the Cretaceous or chalk cliffs of England; the other was formed in most recent time.

Between the Cretaceous and the recognized Pleistocene beds there is a series of sand deposits whose age is not certainly known. Some of the beds along this horizon probably belong to the Pleistocene itself. Others seem to represent an intermediate period known as the Tertiary, and to have been formed in great bodies of fresh water; lakes which stretched from western Iowa to the foot of the Rocky mountains.

The lowest rocks of the region of which we have any knowledge either from exposure or from drill records, are much older than the Cretaceous. These include the Sioux quartzite, popularly known as the "Sioux Falls granite," and certain beds of granite, schist and old lavas which, in Plymouth county now lie buried beneath several hundred feet of later material. These older beds belong probably to the Algonkian formation, and they, doubtless, form a part of a long arm of similar material stretching out to the southwest from the Lake Superior region. The only portion of the series now to be seen is the quartzite itself and certain associated slates and diabase dikes, all found near Sioux Falls.* The surface of these older beds, which at Sioux Falls lie 1,400 feet above sea level, dips to the southeast so that at Hull the old lava beds, which seem to belong to the same formation, occur at 878 A. T. At Le Mars it is 215 A. T. and at Sioux City 135 feet below sea level. These older rocks formed the floor upon which the limestones and associated beds of the Paleozoic were deposited and over the truncated edges of the Paleozoic the Cretaceous beds were laid down. With the Cretaceous begins the portion of the history of the region which it is possible to read with approximate accuracy from the deposits now exposed. The classification of the exposed strata is shown in the table given below.

*See Beyer: Iowa Geol. Surv., vol. VI, pp. 67-112 1896.

GROUP.	SYSTEM.	SERIES.	STAGE.	SUBSTAGE.
Cenozoic.	Pleistocene.	Recent.		Alluvium.
		Glacial.	Wisconsin.	Gravel trains.
			Iowan?	Loess.
				Drift.
	?			Riverside sands.
Mesozoic.	Cretaceous.	Upper.	Colorado.	Niobrara chalk.
				Benton shales.
			Dakota.	

GEOLOGICAL FORMATIONS.

Cretaceous.

The sandstones and associated deposits in the vicinity of Sioux City were among those which were first studied by American geologists, and fossils were collected from them before the Cretaceous, as such, had been recognized in America. The deposits of this region are accordingly intimately connected with some of the most interesting chapters in the development of the science in America. Certain crucial points were first raised because of studies carried on, in part at least, within the limits of this county.* The exposures along the Big Sioux and in the vicinity of the mouth of the Broken Kettle have long been famous, and they show much that is interesting to students of geology. Probably the best single exposure in the county is near the site of the old Crill mill (Sec. 32, Tp. 91 N., R. XLVIII W.). At this point the river

*See, with references, Geol. Woodbury Co., Iowa Geol. Surv., vol. V, pp. 241-299. 1896.

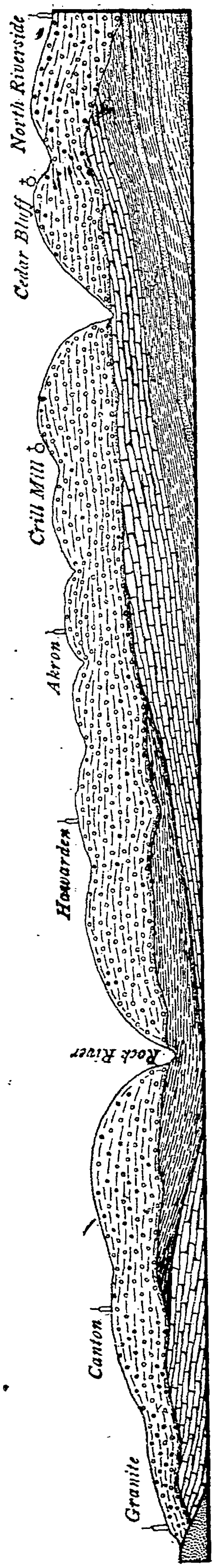


Figure 11. Geological Section along the Sioux River.

has swung in against the base of the bluff so as to cut away the gravel plain and expose the rocks. Below the loess and drift on the hilltops the following beds may be seen.

		FEET.
6.	Limestone, thin leafy texture, full of specimens of *Inoceramus labiatus;* the individual leaves of rock separated by 4 to 10 inches of chalk; exposed at several points along the slope, total thickness indicated.......	90
5.	Shale, buff, sandy, with thin layers of sandstone and ferruginous concretions	30
4.	Shale, dark blue to drab, fine-grained, argillaceous	10
3.	Sandstone, fine-grained, calcareous, light buff to white...........................	15
2.	Lignite	1½
1.	Fire clay, white to light gray, only slightly exposed, found in digging...............	6

The sandstone seen in this section and the beds below represent the Dakota. The shales between it and the overlying chalk belong to the Benton formation. The Dakota and the Benton are shown in Plate xxvi. The chalk of the Niobrara is shown in Plate xxvii. Ordinarily the Benton and the Niobrara are grouped together under the name Colorado.

The beds seen at this point are also exposed not far south in the famous Cedar Bluff* and at intervals between the two exposures. To the north they dip beneath the river, the uppermost beds being last exposed on the Iowa side, between Chatsworth and Hawarden, as shown in Figure 11.

DAKOTA.

The Dakota is one of the more important divisions of the Cretaceous of the interior

*Geol. Woodbury Co, Op. Cit., p. 231.

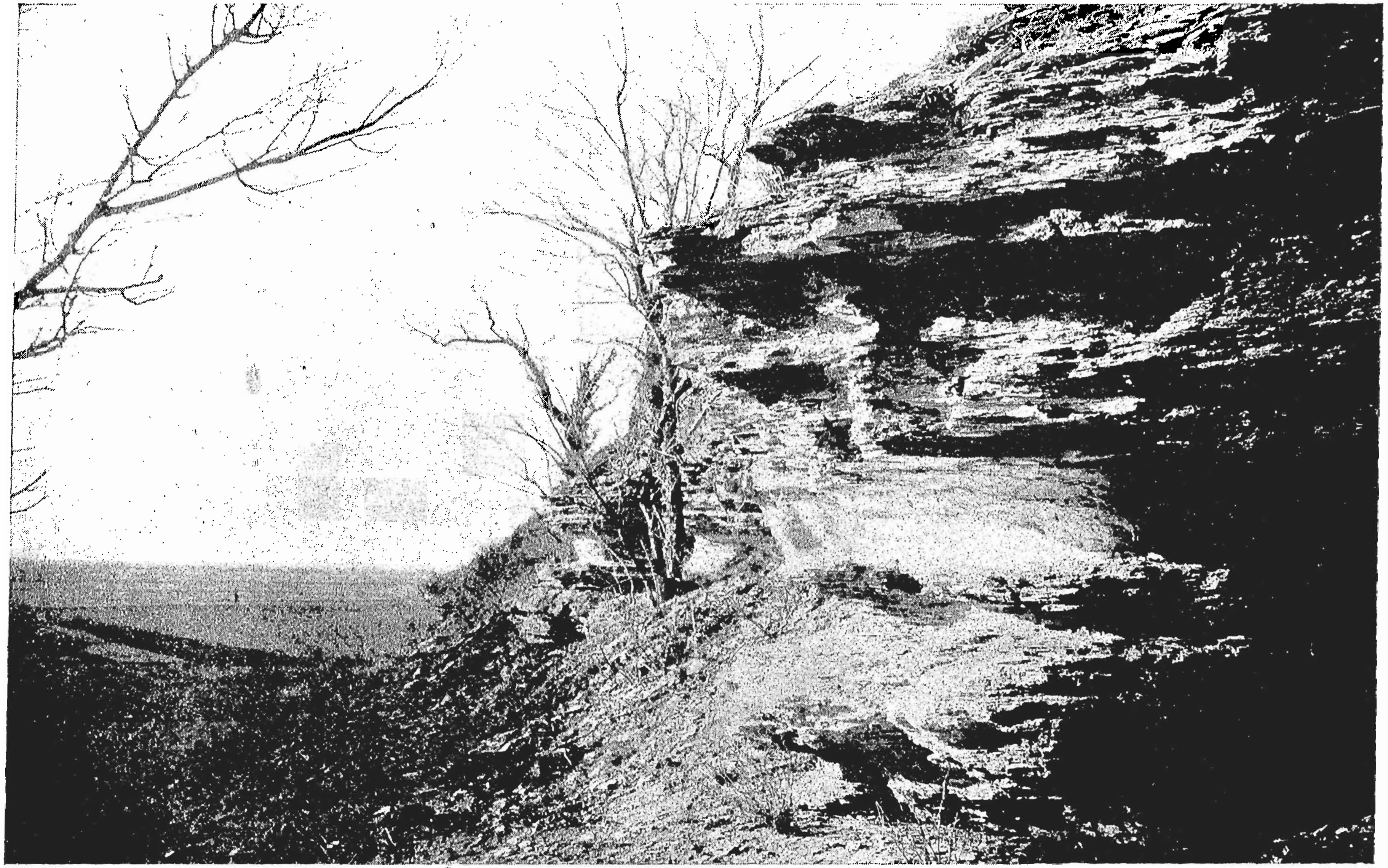
both from its areal extent, stratigraphic significance, and economic value. It outcrops over only a limited portion of Plymouth county, being confined entirely to the lower portion of the Big Sioux valley. As it is found again to the east in Sac, Greene and Guthrie counties and is encountered in well drillings at many intervening points, it is known to extend under the whole county. Over the great plains as a whole the Dakota is essentially a sandstone formation. That portion found near the mouth of the Big Sioux, however, contains a considerable percentage of shale. These shales are well exposed in the clay pits at Sargents Bluff in Woodbury county* and they also occur in the lower portion of the bluffs at North Riverside. The sandstone found at the Crill mill exposure is shown at intervals down the river and forms the top of the formation in this region. It, together with the associated shale, is believed to represent a shore formation while the overlying beds record a period of deepening waters and the deposition of off-shore sediments. It is from the Dakota sandstone that the leaves of the willow and other species of deciduous trees which caused the formation to be originally classified as Tertiary, were collected.† So far no important collections have been made from the Plymouth county exposures, though a careful search would probably be rewarded by numerous specimens.

COLORADO.

The Colorado formation doubtless underlies almost the whole of this county. Its outcrops are, however, confined to the valley of the Big Sioux and the lower course of its tributaries. The only known exception is an outcrop on Deep creek near Le Mars, now reported for the first time. The formation consists, as already stated, of a loose shale member, the Benton, and an upper chalk and limestone member, the Niobrara. The appearance of the latter is excellently

* Geol. Woodbury Co., Op. Cit., p. 260.
† Geology of Woodbury Co., p. 267.

DAKOTA AND BENTON FORMATIONS ON THE SIOUX RIVER.



CHALK CLIFF ON THE SIOUX RIVER.

shown in Plate xxvii, which is from a photograph of a portion of the Crill mill exposure. The thin lamellar character of the limestone is especially characteristic. The proportion of chalk and its purity varies greatly. At Yankton, S. D., and St. Helena, Neb., there are great bluffs of quite pure material. Farther north in the region surrounding Sioux Falls the beds, while not so thick, seem equally pure. Calvin* has interpreted this as meaning that the Sioux City exposures were nearer the shore line, so that the conditions of food supply and growth were not so favorable to the strictly marine chalk-forming types of life, such as Foraminifera. Analyses of the chalk from near Hawarden bear this out, in that they indicate a notable percentage of clay and other impurities. It is also true that toward the southeast the field relations show a transition into hard crystalline limestone and that the chalk beds proper become thinner and thinner.

The thickness of the Niobrara, as a whole, is somewhat variable since its top is a surface of erosion. From the top of the exposed Benton, at Crill mill exposure, to the top of the exposed chalk beds, is ninety feet. It is possible, however, that fifteen to twenty feet of this interval is to be assigned to the Benton. At the Otis mill, in South Dakota, opposite Chatsworth, thirty-five feet of Niobrara strata are exposed between the Benton and an overlying sandstone. Near Westfield, about twenty-five feet is exposed. In general, less than fifty feet of the Niobrara remains in western Plymouth county, though there can be but little doubt that much has been removed through erosion.

From Crill mill north to Westfield, the Niobrara forms a very sharply defined terrace in the hillsides. This terrace slopes gradually to the north with a dip of about six feet per mile. This does not seem to be the true dip of the strata, since, taking the top of the Benton as a guide, the latter is found to be a little less than two feet per mile. The top of the terrace marks, so far as can be determined, the upper surface of the

*Composition and Origin of Iowa Chalk. Iowa Geol. Surv., vol. III, pp. 211-236. 1893.

Niobrara. It seems to be a very even erosion surface and the figures would indicate that, since the Niobrara was cut down to that level, the strata have been given a northward tilt of about four feet per mile. To the north, in Sioux county, the Niobrara is covered by a series of blue-black shales which have been referred to the Pierre*. These are exposed about four miles below Hawarden (Tp. 94 N., R. XLVIII W., Sec. 15), where the following sections may be seen below the drift.

	FEET.
2. Shale, drab to blue, argillaceous in part, with numerous selenite crystals	25
1. Limestone, fossiliferous, thinly-bedded, with chalky layers	20

If the plane formed by the top of the terrace mentioned be projected, it would just about touch the top of this exposure. The erosion accordingly which developed the plane was probably later than the Pierre shales. At the Otis mill, however, there is a sandstone, to be later described, which rests upon this plane, and the period of erosion which developed the latter may accordingly be fixed as between the deposition of the Pierre shales and the Otis mill sandstone.

The exposure of Niobrara near Le Mars is found, on the Koons farm (W. ½ of Sw. ¼, Sec. 2. Tp. 92 N., R. XLV W.), on the west side of Deep creek. A thickness of about twelve feet is shown and the outcroppings occur along the stream for about 100 yards. It is possible that the Niobrara thickens under the hill, but there are no data bearing on this point. Both chalk and soft thin-bedded limestone occur. *Inocermanus labiatus* is very abundant. The base of the Niobrara is about 1,225 A. T. and is marked by a magnificent spring. Below the Niobrara, at a bend in the creek, about four feet of the Benton is exposed. It is here a blue-black, apparently unfossiliferous, clay shale with large septarian nodules. This is the only known natural exposure of rock in Plymouth county east of the Sioux valley, though the rock is known through wells and

*Iowa Geol. Surv., vol. III, pp. 112-114. 1894.

borings at several points, and other exposures may be expected to be found. The deeper streamways, both of this and Woodbury county, have been cut below the level of the upper surface of the rock. The lack of exposures is due to the drift filling of the valleys. The rock, however, is near the surface, as is shown by a well near Seney which was put down on the Kent land (Tp. 93 N., R. XLV W., Sec. 28, Se. ¼) and started at about 1,230 A. T. The well was begun with a three-foot auger and carried down with this into the Benton shale so that there can be no doubt as to the identification.

		FEET.	INCHES.
8.	Black soil	5	
7.	Yellow clay (drift)	20	
6.	Black clay shale (Benton)	85	
5.	Sandstone		1½
4.	Light clay shale	10	
3.	Sandstone		1½
2.	Pink clay	10	
1.	White sand		

Probably all the beds below the black clay shale are to be referred to the Dakota.

The usual character of the Benton is shown in the Crill mill section (see Plate xxvi). There are two divisions, an upper sandy shale and a lower, more argillaceous portion. These are well marked at the exposures down the river and may be seen at North Riverside. In the opposite direction these divisions seem to lose their identity. Near Westfield on one of the Van Vlyck farms (Nw. ¼ Sec. 13, Tp. 92 N., R. XLVIII W.) in making an excavation for a barn, the drab clay shale was found immediately below the Niobrara, as shown in the section given below.

		FEET.
2.	Limestone soft, thin-bedded, with chalky layers	25
1.	Shale, drab dark, argillaceous, with ferruginous nodules and some sandy portions	10

There was some slight evidence of disturbance here but at the Otis mill, opposite Chatsworth, the same relations were found with no evidence of movement. The section at this point, which is interesting from several points of view, is given below.

		FEET.
6.	Loess, sandy, with many lime concretions, rising over the bluffs	20
5.	Drift, new, fresh pebbles, yellow color, and with slight traces of a soil at top	30
4.	Old soil, black to drab, sandy	2
3.	Sands, white to lemon yellow, very fine-grained above, becoming coarser and orange-colored below	10
2.	Niobrara, principally thin shelly limestone with a few chalky streaks	35
1.	Shale, black to drab, with poorly developed laminations	20

The hill rises here to a total height of 190 feet, the added thickening being probably in the drift and loess. Excepting the Pierre shale already mentioned the sands and old soil seen here are the only beds, other than the drift, found above the Niobrara in this immediate region. Whether the Pierre shale extends over any portion of Plymouth county is wholly unknown. There are no exposures showing it, but there are considerable areas in the northwestern townships where it may be concealed beneath the drift.

The Otis mill sands or sandstones are of considerable interest. As has been seen they are probably separated from the known Cretaceous by a considerable interval of erosion. The presence of a marked soil separates them sharply from the known drift. In stratigraphic position they are akin to certain problematic sands already known in the region, and first noted by Todd* who has also noted their probable presence beneath the drift at Le Mars.† Fossils have been found in the beds‡ but their age can not be definitely stated. They may be anything from late Tertiary to early Pleistocene. In the present instance there is even wider latitude of interpre-

*Proc. Amer. As. Adv., Sci., vol. XXXVII, pp. 202-203. 1889.
†Proc. Iowa Acad. Sci., vol. I, pt. ii, pp. 14-15. 1892.
‡Geol. Woodbury Co., pp. 275-279. 1896.

tation since the beds may belong anywhere between the Cretaceous and a late drift, probably Iowan. In appearance the sands differ somewhat from those found at Riverside. They are more highly colored and remind one of river deposits. They contain fragile and much rotted bivalve molluskoid fossils, which are not sufficiently preserved to allow specific determination. They seem to be Unios. The Riverside sands in their usual character are seen southeast of Akron (Ne. Sec. 7, Tp. 92 N., R. XLVIII W.), below waterlaid beds probably of the same age as the drift of the region.

Pleistocene.

GENERAL DESCRIPTION.

There are two important series of deposits in the county, which had their origin in Pleistocene time. These are the drift and the loess. The former is rarely exposed; the latter is widespread, forming the surface material over almost the entire county. Over the bottom lands there is a third formation, the alluvium, which, however, is largely derived from the loess. The modern streams are usually cutting in the alluvium, and as a result it is only occasionally that a cut along stream or railway is deep enough to expose the drift. One of the best of these exposures is on the Illinois Central railway, immediately east of Remsen. It is shown in Fig. 12. In this exposure there is a core of drift, having the shape of the present hill. It is composed of yellow bowlder clay,

Fig. 12. Section on Illinois Central Railway east of Remsen.

carrying many flattened and striated erratics, fresh and hard. There are little or no signs of weathering. There is no ferretto zone, and little sign of leaching or oxidation. The bowlders and pebbles include granite, coarse with red feldspar, and fine-grained gray, together with limestone chert, greenstone and diorite. Over the drift is a covering of loess of the usual open texture, and buff color. It is a little sandy, carries lime concretions and no fossils. It is about six feet thick. This exposure shows the normal section for the region, except that there no stratified beds are shown. Such beds, however, occur in the vicinity. Exposures of bowlder clay are really unusual, the stratified drift being more frequently seen. Bowlder clay is, however, found frequently enough to establish its presence and reveal its character.

Immediately west of Dalton (Se. Sec. 11, Washington Tp.), there is an exposure which shows certain phenomena additional to those at Remsen. Dalton itself is situated in the broad valley of West Floyd, shown in Fig. 1, Plate xxviii. The hills on the west rise 100 feet above the railway station on the bottom land. In a wagon road cut in one of these hills is the exposure in question. Fig. 2, Plate xxviii.

The drift here is, as usual, fresh and the bowlders are hard. They indicate the usual materials, quartzites, granites, greenish sandstone, limestone and chert. The pebbles are flattened and striated as usual. The drift is, however, a little more pronounced in color towards the top, the yellow being more intense and less buff. Acid tests show that it has been leached quite thoroughly to a depth of one and one-half to two feet, and less thoroughly to a distance of three feet. On the north

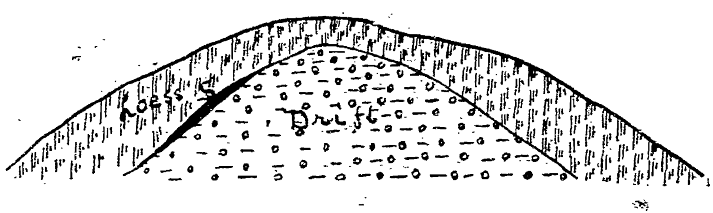


Fig. 13. Drift, loess and old soil west of Dalton

flank of the hill there is a bit of old soil, drab to black in color, and twelve to eighteen inches thick. (Fig. 13.) The slopes of the drift hill were steeper than those at present existing, as is shown by the contours of the two surfaces. The loess, however, thickens on the flanks of the hill. The loess itself is of the ordinary character, being unfossiliferous, not par-

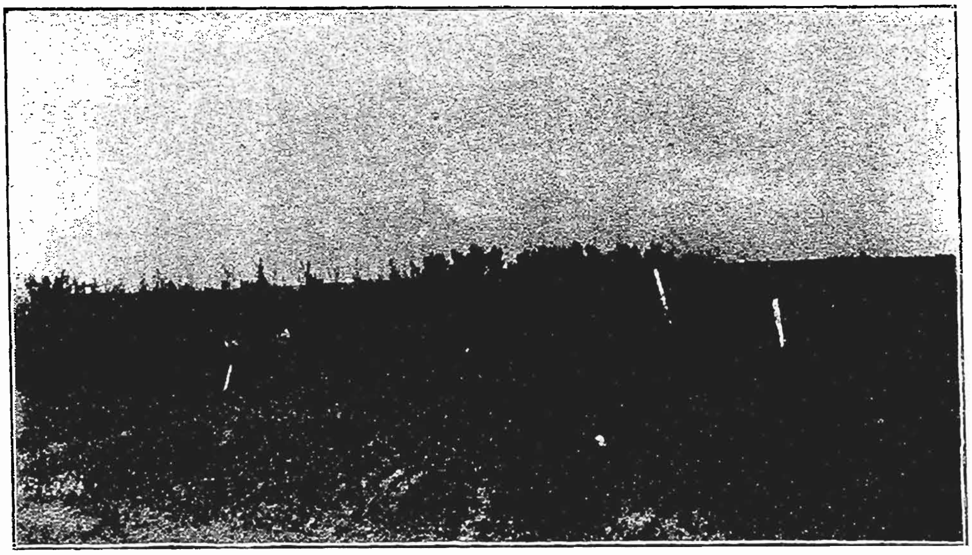


FIG. 1 Valley of Floyd at Dalton, Plymouth county.

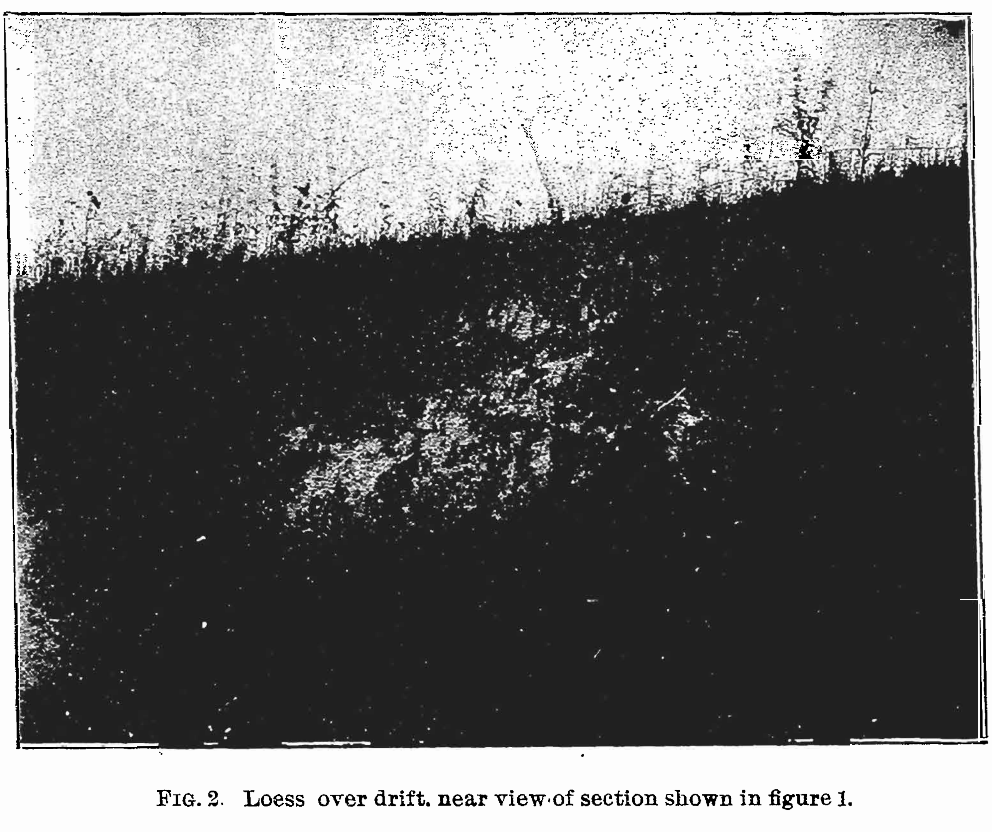


FIG. 2. Loess over drift, near view of section shown in figure 1.

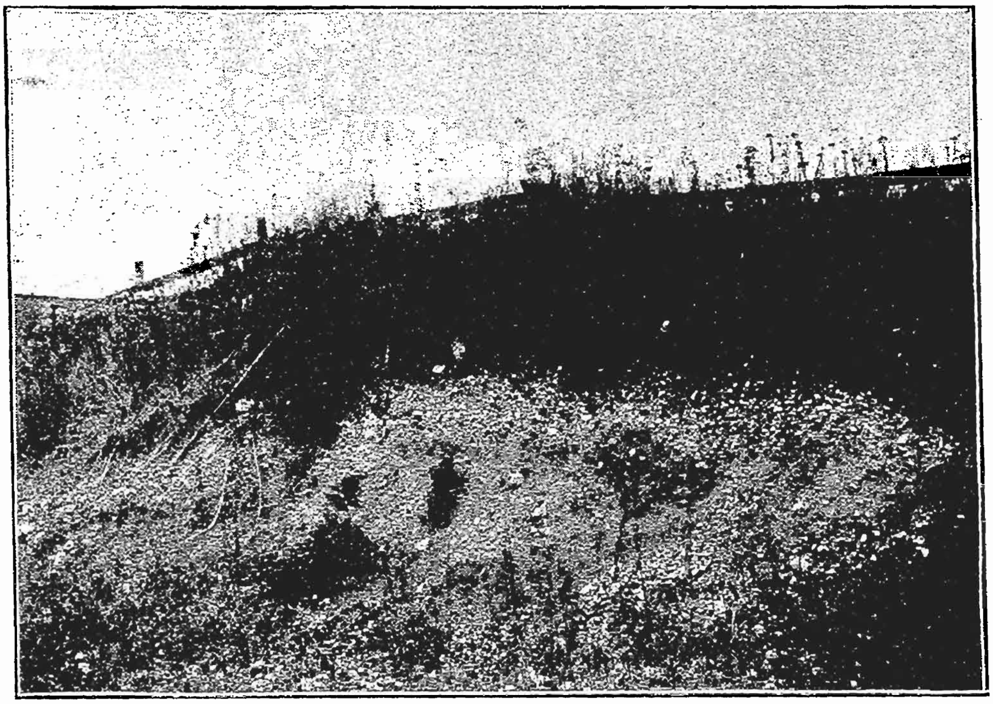


FIG. 1. Loess over drift near Akron, Plymouth county.

FIG. 2. Loess and stratified drift in the pit of the Le Mars Brick and Tile company, Le Mars, Plymouth county.

ticularly sandy, and carrying loess kindchen. These two exposures illustrate well the drift of the region. Along the Big Sioux, in the southwestern portion of the county, there are exposures showing a greater thickness, but the character of the material is the same. See Fig. 1, Plate xxix. In the northwestern portion of the county the loess is occasionally thin or entirely removed, and the hillsides are then bowlder-studded. Slopes, showing bowlders as thickly strewn as in the Iowan drift regions in eastern Iowa, may be seen in Portland township (Sw. Sw. Sec. 1, Nw. Nw. Sec. 12). Not very far from this locality (Sec. 7, Preston Tp.), there is a surface bowlder of grey granite, measuring 7x3 feet, and projecting two feet from the ground. Its surface shows a fine wind polish. In the counties to the north, notably, near Hawarden, in Sioux county, there are some remarkably large surface bowlders, and in Cherokee county, a few miles south of the town of the same name, is Pilot Rock, a Sioux quartzite bowlder, measuring 50x35x12 feet, as now exposed.

Stratified beds occur in the vicinity of Remsen and may be seen near the city dump (Ne. of Ne., Sec. 6, Tp. 92 N., R. XLIII W.). The beds exposed here are on the bottom land where the stream has been thrown against the side of the valley in such a manner as to cut away the alluvium. The exposure shows about six feet of rudely stratified coarse gravel. The material includes numerous bits of granite, Sioux quartzite, white quartzite, limestone, diorite and greenstone. The bowlders are, without exception, fresh and unweathered. Many are flattened, and some show half-effaced striations. With the gravel is a little clean white sand.

Stratified beds similar to these are found at several points in the county, being the beds most usually seen when the loess is cut through. They are found southwest of Remsen (Sec. 2, Marion Tp.), near Kingsley, in the valley of Little Sioux in Elkhorn township (Sec. 30 Sw. Sw.), at Le Mars, on Indian creek near Chatsworth, southeast of Akron and at several other points. At the Kingsley exposure the loess is at its base interstratified with the sand, and pebbles are found in it up to a distance of four feet from its base. At Le Mars the Brick and Tile Co. operate pits located on the bottom land of the Floyd. The loess is five to eight feet thick and is somewhat plastic but usually quite friable. In color it is mainly buff, but there are some horizontal bandings of yellow and blue-drab. It carries a few lime balls which are usually in distinct bands. It rests on stratified gravels and is in its lower portion quite distinctly stratified. Fig. 2, Plate xxix. The gravel bed under the loess is about three and one-half feet thick. The material is fresh, hard, and well rounded. It carries the common drift pebbles, white quartz, pink quartzite, gray and red granite, red porphyry, greenstones, gabbros, cherts, etc. At one point there is a Sioux quartzite bowlder a foot in diameter in the midst of the gravel. Cross-bedding is common. Under and with the gravel is fine, sharp-grained white sand as much as five feet thick. There are also thin streaks of blue clay free from pebbles. The material shows the action of rather strong currents and, with the but half-effaced striations on the pebbles, suggests that it is not a secondary deposit.

On Indian creek near Chatsworth (Se. of Ne. Sec. 10, Portland Tp.), in connection with a limited exposure of Niobrara, there are white and orange-colored sands interbanded with about four feet of a drab plastic clay, resembling in some particulars the gumbo of the southern portion of the state, Southeast of Akron (Secs. 7 and 8, Tp. 92 N., R. XLVIII W.). is an exposure of similar beds. The overlying material seems at first glance to be loess, but a close study shows that it is really a sand coarser in grain than is found elsewhere at the loess horizon. Below the sand and clay is a bed of sand of different constitution, already described as possibly of Tertiary age.

Throughout most of the county the stratified drift is found in the valleys only. In the Akron exposure and at some other points it is seen well up above the river. At Dalton the stratified beds occur some considerable distance above the station. When allowance is made for differences in altitude, it seems not unlikely that these water-laid beds found below the loess were laid down at a fairly uniform horizon and that they represent general conditions and not local accumulations. The material was evidently derived from the drift of the region and in many cases the large number of bowlders still showing striations indicate that it was not much, if any, reworked. The stratified beds may be a little younger than the drift but it is believed that there is not very much difference in age. It is, of course, possible that some of the beds really represent local accumulations of material gathered from the surface of the drift. This is especially apt to be true of some of the valley deposits of the eastern portion of the county. The upper gravels of the western portion are. however, quite certainly older than the major erosion of that region, and there seems no sufficient reason for assigning the erosion of the two parts of the county to different periods. Despite the fact that the loess and stratified drift are occasionally interbedded, it is believed that they are of somewhat different ages. This is held because the underlying beds are apparently independent of the present topography, while the loess is manifestly later. The two deposits are separated by whatever interval was necessary for the erosion of the valleys of the region and for the leaching of the drift with the development of the soil. That the beds should be occasionally interbedded seems not unnatural in view of the loose nature of both deposits.

Later than the loess just described, which represents the general sheet already mentioned as spreading over the major portion of the county, is the Wisconsin gravel train, occupying the valley of the Big Sioux and affording the fertile bottom land upon which Hawarden, Chatsworth, Akron, Westfield and the other valley towns are built. The railway runs along this terrace so that the elevation of the stations mentioned gives the elevation of its surface. At Hawarden and elsewhere the bottom land has been cut into, and the underlying sands and gravels may be seen. At this point the river is about twenty-five feet below the town and has a newer and narrower terrace barely ten feet above its waters. Near the mouth of Broken Kettle creek there is a higher terrace very faintly cut in the loess. Its upper surface is marked by the presence of Unios forty-five feet above low water in the Sioux. This level corresponds to the flat and well-marked bottom land found in the upper portion of Broken Kettle creek as already noted. The terrace, then, marks a stage in the waters later than the deposition of the ordinary upland loess, but earlier than the thick loess near the river which bears the marks of wind action. The Unios occur in little groups or colonies, nested together along this horizon, and at the same horizon ordinary loess fossils also occur. The same phenomena are found in Woodbury county at North Riverside, though at a lower horizon relative to present water level. In Monona county near Castana and Turin there is a very well-marked loess terrace, about seventy feet above the river and similar terraces are common in the region. These terraces must be interpreted as meaning various changes of a water level, over an area of more than local extent.

There is only very uncertain evidence of a drift older than the one exposed. Within the county there are no exposures showing glacial deposits older than the surface drift. Owing to the presence of the soft blue shales of the Cretaceous immediately below the drift it is not always possible satisfactorily to interpret such well records as are available. Forest beds have been reported from time to time throughout the northern and eastern portion of the county. In the H. Dethoff well (Se. Sec. 17, Elgin Tp.), one is said to have been encountered at a depth of ninety feet, after passing through a blue clay. Lighter, colored clays were found beneath. One mile west and two south of Marcus in Cherokee county a yellow pebble clay was reported between two blue clays. Such a succession is also reported occasionally in Plymouth county and would find its best explanation in the assumption of two drifts. The drift as reported from wells is quite thick. Near Carnes in Sioux county it is said to be 190 feet, near Orange City about the same, at Kingsley 150 to 250, and at Marcus, which is on a high divide, 400 feet of drift is reported. It is very probable that these figures include the shales of the Benton and Dakota and are really depths to the Dakota sandstone, though in the case of the Marcus well indubitable drift pebbles, said to have come from the bottom of the well, were shown. Until, however, we have the record of a well put down under the supervision of a geologist or a very careful set of samples, our interpertation of these facts must wait.

SUMMARY.

The drift series of Plymouth county, then, consist of the following members: *First*, a possible older till sheet; *second*, a well developed till with associated stratified beds, the whole relatively fresh and young, and yet having an upper surface which, occasionally at least, shows leaching and the development of the soil; *third*, a general but thin sheet of loess spread over the whole county and largely concealing the underlying beds; *fourth*, the Unio terrace of Broken Kettle creek; *fifth*, the heavy loess of the Missouri bluffs, beginning at this time, but still being deposited; *sixth*, the Wisconsin gravel terrace of the Big Sioux valley.

AGE OF THE BOWLDER CLAY.

In order to properly appreciate the significance of the Plymouth county exposures, it will be necessary to recall certain general facts as to the drift sheets of Iowa. Of the earliest of these, the pre-Kansan, so little is known that for present purposes it may be altogether neglected. If it ever existed in the region under discussion, all traces have doubtless been swept away by the later ice invasions. The second, or Kansan, is the drift sheet which covers so large a portion of southern Iowa, and adjacent portions of other states. It is a very old till and its upper surface is marked by much leaching, oxidation and ferrugination. It is covered by a mantle of loess which is normally of the older or white clay phase, being more plastic and less porus than the loess seen in northwestern Iowa. Towards the central portion of the state, however, the loess, overlying the Kansan, takes on a more friable character. Between the deposition of the Kansan drift and the loess which covered it, was a very long period of erosion, as is shown by the topography and the ferrugination, leaching etc., already mentioned. Sometime within this period, an ice sheet crossed Illinois from the northeast, and invaded the southeastern portion of Iowa. This ice sheet (Illinoian) is presumed to have come from the Laurentian center of dispersion, while the preceding Kansan invasion came from the northwest, and represented the Keewatin ice sheet. Succeeding the Illinoian invasion, after a considerable interval, was the Iowan, in which the ice covering Iowa came again from the northwest. The drift laid down by this ice sheet is well developed in northeastern Iowa, and in that region it was first studied. In northeastern Iowa it is intimately associated with the loess, the latter occasionally lapping up over, but being more commonly spread out from the edge, occupying in fact the position of an outwash. Indeed there can be but little doubt that the bulk of the loess of eastern and southern Iowa is of Iowan age. It is important to note, however, that in the type locality the loess does not cover the Iowan drift, and that throughout the extent of the latter in the northeastern portion of the state, instances of such a relationship are rare, if not entirely absent. Later than the Iowan was the Wisconsin. One arm of this ice ran down in the form of a long tongue from the Iowa-Minnesota boundary, covering the area between Spirit and Clear lakes, and extending to Des Moines. Another lobe occupied that portion of South Dakota lying between the Big Sioux and the Missouri rivers. The moraine, bounding these two lobes, is known as the Altamont and its two branches join not far north of Sioux Falls. Plymouth county is accordingly outside the Altamont moraine. whose nearest point due east is Storm Lake. On the west the moraine comes to Beresford and Brush creek, about twelve to fifteen miles west of the Big Sioux.

The Altamont moraine has been considered to mark the limit of the Wisconsin drift, and in the region to the east of the Des Moines lobe the extra-morainic drift is Iowan. At the southern end of this lobe there is an overlap and the Wisconsin rests upon the Kansan with the loess lying unconformably between. In Iowa no Illinoian has been recognized except in the southeastern portion of the state. It is possible, however, that when the ice advanced from the northeast there was a corresponding advance from the Keewatin area. At least, it is difficult to conceive of climatic or other changes which would bring about glaciation in the Laurentian region without affecting to some degree, at least, the western region. In considering, then, the age of the Plymouth county drift, there are three possibilities.

a. The drift may be Kansan.

b. It may be Illinoian.

c. It may be Iowan.

In view of the peculiar position of the area, in a notch between two lobes of the Wisconsin, it is a question whether we are justified in considering it demonstrated that the Wisconsin is everywhere terminated by a definite moraine so that a fourth possibility remains to be considered, viz:

d. Is the drift an older extra-moranic Wisconsin?

It is probably impossible with the data now at hand to fix absolutely the age of the drift. Much can, however, be done to solve the problem and some factors of doubt may be eliminated.

In the correlation of the different drift sheets there are four main sets of phenomena which may be used. These are *a*, topographic development; *b*, physical character; *c*, alteration, and *d*, stratigraphic relationship. These are not all of equal value, perhaps, and their value also varies in individual cases.

Topographic Development.—Considering first the topography of the region it may be stated at once that the relationship is strongest with the Iowan. The completeness of the drainage and the absence of sloughs, when one considers the extent of country of which this is true, sets it off from the typical Wisconsin. Indeed, judged by this factor alone, the drift of northwestern Iowa might be even older than the Iowan, and apparently approaches the Illinoian. Apparently the drainage basins are not quite so well developed as is common in areas covered by the latter drift, but this may be only apparently true, or may be due to special causes.

As compared with the Kansan the topography is much younger. The valleys are not so deep nor are the bottom lands so extensive. The Floyd at Dalton has cut only 100 feet below the upland, though at Sioux City, twenty-five miles away, the water level is 136 feet below Dalton station, or at least 120 feet below the present river level. It is true that the presence of the Unio terrace indicates that for a time, at least, the water level at Sioux City was somewhat higher than it is now, so that the cutting power the Floyd has probably not been always the same. Nevertheless in view of the favorable conditions for erosion, the shallowness of the valleys as compared with those of the Kansan region can not be considered as other than an indication of a shorter period of erosion.

Alteration.—The amount of alteration which the material of a drift sheet has suffered, when it can be shown that this alteration has taken place since the deposition of the drift, is an important index to the length of time that the drift has been exposed. The alteration of the Kansan drift material is one of its most prominent characteristics, while Wisconsin has suffered no alteration, and the Iowan usually none, but occasionally a little. The drift of northwestern Iowa is much too young and fresh to be Kansan. There is an entire absence of the ferretto horizon, and of the soft, badly-weathered bowlders. The granites are almost without exception fresh and hard. Indeed the drift contains less old material than is found in the typical Iowan of northeastern Iowa. This may, however, be due to the fact that the latter is apparently much thinner, and accordingly material derived from the old drift and incorporated in the new would have more opportunity to be exposed than in northwestern Iowa. In the latter region only a very few instances of decay of bowlders *in situ* have been noted and in these cases the amount of decay was much less than is customary in Kansan regions.

In the matter of leaching, the northwestern drift seems on the whole to have suffered more than that in northeastern Iowa, and to resemble most closely in that particular the Illinoian. A really valuable generalization on this point can not, however, be drawn without wider studies, since it is not known how extensive the leaching phenomena may prove to be. It is certainly true, however, that the leaching is greater than that suffered by the Wisconsin, and in so far these facts would suggest that the drift is older than the latter. It is also true, as already shown, that the leaching took place in the interval between the deposition of the drift and the loess.

Physical Character.—Nothing distinctive in physical character been observed to be true of the northwestern drift. Possibly its color is a trifle yellower than the Wisconsin, it approaching in that matter the Iowan. At Storm Lake, and again near Carroll it was observed that the Altamont moraine and the country inside it showed abundant large surface blocks of limestone, presumably Winnipeg. These blocks are not so abundant upon the outer drift, and to that extent there seems to be reason for believing that there was some difference in the source of the material as well as in the direction of ice flow. It may be noted in passing that all that is known of the Iowan in northeastern Iowa and much of that known of the drift in northwestern Iowa indicates that the ice had an important movement toward the east. The Wisconsin, however, as evidenced by the Des Moines lobe, and to a less extent by the Dakota lobe, had an essentially southern movement, deploying about equally to the east and west. These facts would agree with the evidence derived from the Winnipeg limestone and strengthen the argument for separating the extra-morainic drift from the Wisconsin.

Stratigraphic Relationship.—The relations of the Iowan to the loess have heretofore afforded great aid in working out the stratigraphy of the drift series. In the regions so far studied the Iowan has been found practically, if not wholly, free from a loess covering. The drift of northwestern Iowa is, however, buried beneath a well developed loess sheet and furthermore the loess is separated from the drift by the interval, whatever the time value of the latter may have been, in which the erosion, leaching and soil-making noted in the description of the deposits, occurred. Now, if the loess represents a single period of deposition, the northwestern drift is probably much older than the typical Iowan and might be, judged by this standard, either Illinoian or Kansan. Few, probably, would care to maintain that the loess is all contemporaneous. It has, however, been urged, and with good reason, that the bulk of the loess was contemporaneous with the Iowan. That the period of retreat, probably, of the Iowan ice was a period in which the general conditions favored loess deposition. It has been at the same time urged that the Wisconsin as a whole was marked by fringing and outwash deposits notably coarser; gravel trains and similar phenomena which, it may be remarked in passing, are quite characteristically developed in the region under study. These differences between fine and coarse outwash deposits have, furthermore, been considered to be due to general conditions of the altitude of the land and the changes to hinge on earth movements of some extent. The probabilities, then, in the case of a broad area covered by a uniform mantle of loess and cut by valleys filled with later Wisconsin gravel trains, certainly favor the idea that the loess is of Iowan age and the underlying drift, in this case, older. Furthermore, in the case in question, the loess may be traced south to where it overlies an undoubted

Kansan till; and so far the data for drawing a border line between the loess sheets are not altogether satisfactory. If, then, the underlying drift in the present case be Iowan, as many of the phenomena suggest, the loess is evidently a very exceptional body and requires a special explanation.

The difficulty would be readily solved if one were to accept the hypothesis that the loess were a wind deposit; but that hypothesis seems less applicable to the deposits in question than to almost any other loess of the Mississippi valley. The hypothesis must face the serious difficulties (1) that the Minnesota geologists have found it to be practically limited by the 1,500-foot contour,* and (2) the fact that the most probably wind-deposited loess of the Missouri bluffs exhibits a totally different behavior, as already noted. It is true that the character and topography of a wind deposit is largely influenced by the nature of the vegetation. The sand dunes at the southern end of Lake Michigan take the ridge form around groups of small pine trees, and in general an evenly spread grass, such as covers our prairies, seems to induce a sheet-like deposition of wind materials. The Dutch engineers understand this so thoroughly that they use grass to make the sea winds build dykes wherever they will, and they manipulate it so as to get any desired forms.† In the present case, however, both the contrasted areas have the same vegetation and there is no reason to believe that there have been differences in this regard. For the sheet-loess covering northwestern Iowa, the hypothesis of water action in some form seems on the whole best.

It would seem evident from the facts of the erosion and leaching of the underlying drift as already mentioned that the loess is much younger than the latter. This would, if the drift be considered to be Iowan, require the presence of a considerable body of water in the region at a period long subsequent to the retreat of the Iowan ice. The most ready

*Winchell: Final Rept., vol. I. Minn. Geol. Nat. Hist. Surv., pp. 543-545.
†Corthell, E. L., Eng. Mag., 409, Dec., 1897.

suggestion is obviously that this occurred when the Wisconsin ice occupied the Altamont moraine. It is true that the loess sheet maintains itself on the east up to the Altamont moraine. It is characteristically displayed west of the latter at Storm Lake, and as far south as Carnarvon, in Sac county. To the north, as has been said, it is limitedly approximately by the 1,500 feet contour, and does not reach quite to the moraine. On the west it extends up to the moraine* along Brule creek. At Storm Lake there is at one point slight evidence that the moraine is younger than, and rests on, the loess, though it has so far proven impossible to get any general or clear evidence bearing in this direction. It should be recalled that at the southern end of the Des Moines lobe, where the Wisconsin rests on the Kansan, there is clear evidence of the loess passing under the former drift. It is also to be remembered that along the eastern side of the Des Moines lobe there are no extensive loess deposits and that in general loess is not found in connection with the Wisconsin. Under exceptional circumstances it has, however, been noted in Wisconsin by Salisbury† and in Peoria county, Illinois, by Leverett.‡ In the present case the topographic distribution of the loess would certainly seem to favor the idea of an age relationship between it and the Wisconsin, and would indicate that this loess belongs in the exceptional category. Such a reference, however, meets the difficulty that the loess, a fine material requiring quiet water for its deposition can not be easily believed to have been deposited over so broad an area in connection with an ice sheet which everywhere else is fringed by gravel and running water deposits, and which even here, shows the usual gravel trains.

The character of the deposits made by the streams flowing from a melting ice sheet would be largely a matter of the competency§ of the streams. This, in turn, is dependent upon

*Todd: Private communication.
†Salisbury: Jour. Geol., vol. IV, pp. 929-937. 1896.
‡Private communication.
§Gilbert: Geol. Henry, Mts., p. 110. 1877.

their velocity and volume, and these are factors of the rate of melting and the declivity. The attempt has heretofore been made* to explain the phenomena mainly as due to differences in the declivity of the stream courses, and the rate of melting, which would at any given time condition the volume of water present (the declivity remaining the same), has been thought to be a minor factor. If one is to accept the correlation suggested and assign the loess in question to the Wisconsin, it may be needful to take the rate of melting more into account. It is obvious that with a smaller volume of water, the declivity remaining the same, the competency, as well as the capacity, of the stream becomes limited. If, on the other hand, the volume of water is augmented so greatly as to produce a pounded condition, the same result is reached. It seems possible that the latter may have been the true condition in the present case though nothing more than the suggestion can at present be made. The matter is one of such grave difficulty that the determination of the nature of the process may well wait on conclusive evidence as to the facts.

All the classes of evidence noted united in showing that the drift can not be Kansan. The limited amount of erosion which it has suffered, the general absence of weathered materials, and the small amount and possibly local character of the leaching, all set it off from the deeply eroded, much weathered and highly colored drift of southern Iowa, which is universally leached, often to depths of nine or ten feet. In stratigraphic position alone does the drift seem to correspond with the Kansan and its correspondence in this particular is no closer than with the Illinoian. With regard to the latter it is by no means certain that, when isolated, patches of Illinoian drift can as yet be discriminated. The drift of northwestern Iowa corresponds to the Illinoian in position, in relation to the overlying loess, and so far as tested, in the amount of leaching which it has suffered. Topographically the area seems younger than a typical Illinoian region. The streams have

*Iowa Geol. Surv., vol. VI, p. 462.

not reached grade nor are they apparently so near it as in Illinoian regions. Since the controlling stream level, the Missouri at Sioux City, has cut some distance below the general plane upon which the Plymouth county streams are working and the latter have high grades it is difficult to suppose that the time of their activity has been long. It is also true that the general appearance of the drift is fresher than the Illinoian of southern Iowa. It is conspicuously less highly colored.

If the drift be considered to be Iowan one would expect to find in conformity with its behavior elsewhere, extensive loess deposits contemporaneous with its maximum development. In Woodbury county near North Riverside, there are phenomena bearing on this question.* It consists of an interbedding of loess and till in such manner as to leave no doubt that the two deposits are of the same age. When first seen, because of the distance of the exposure from any other known young drift, the deposit was referred to berg action at a period when the ice stood in the Altamont moraine. Later visits to the exposure in company with R. D. Salisbury has led the writer to the belief that the deposits was made by land ice and work of the past field season, by showing the presence of the young till in Prospect Hill Sioux City, and in Ida and other counties far south of what was at first considered its probable southern boundary,† offers a ready explanation of the phenomena.

The balance of evidence would seem to indicate that the drift is either Illinoian or Iowan, and since it has already been provisionally referred to the latter it may for the present rest in that category. Clearly it is not Kansan, and while certain illusive evidence not yet well enough in hand to discuss, seems at times to link it with the Wisconsin, the bulk of the phenomena seems to indicate an earlier age.

There are traces of Kansan drift at several points in the region discussed. At Sioux City there are certain old gravels

*Todd and Bain: Proc. Iowa Acad. Sci., vol. II, pp. 20-23. 1895; Bain: Geology Woodbury county, pp. 283-284., 1893.

†Iowa Geol. Surv., vol. VI, pl., xxviii.

which can hardly be referred to anything younger. Near Sioux Falls similar old material has been noted, and at Correctionville, the drift deposits locally include patches which must have been derived from an older till. Well to the north of Crawford county, the Kansan outcrops with all its characteristic features. In southern Carroll county the Kansan is also well shown. In this county, by the way, the three drifts are present and well displayed. The Kansan and Iowan (?) are sometimes confused along the border between the two, and the scarcity of exposures and the thickness of the loess renders it impossible to trace the border line as readily as in eastern Iowa. Without considerable detailed work it can only be outlined as running from Carroll northwest through the northern tier of townships in Crawford county.

ECONOMIC PRODUCTS.

Clay.

Plymouth county is excellently supplied with raw material for many lines of clay goods. The brick clays include material suitable for several grades of building and fire brick, and possibly by combination pavers could be made. One of the beds of clay present could, perhaps, be used for stoneware, and by other combinations sewer pipe and drain tile may be manufactured. Both the surface and the underlying formations are clay-bearing. The Dakota and the Benton divisions of the Colorado contain fine clay beds yet unused. The loess, the most valuable clay bed of the drift series, is widely distributed, and is now in use at Le Mars. At present the county produces building brick only.

The bed of fire clay noted in the Crill mill section is of very good quality. It is of a white to gray color, contains very little grit, is quite plastic and would apparently be easily worked. It lies immediately below a thin bed of lignite which, in turn, as shown by the section previously given, is below a heavy sandstone. At most stages of the water the clay could be mined by simple drifting, the sandstone forming a good roof. Some exploration in the vicinity shows that the bed is at least six feet thick. The exposures are not on a railway line, though there is an excellent wagon road from them to Westfield. The same clay could probably be obtained by sinking a shaft to it at some point along the valley north of the outcrops. It rises in the hills to the south, and has been mined at North Riverside in Woodbury county.

The following analysis, made by Prof. G. E. Patrick, shows the quality of the clay. For comparison analyses of certain standard fire clays are also given.

	I.	II.	III.	IV.	V.	VI.	VII.
Silica $Si O_2$	67.42	86.63	55.11	65.10	58.76	54.65	56.01
Alumina $Al_2 O_3$	19.93	10.92	26.71	22.22	25.10	30.74	31.68
Iron $Fe_2 O_3$	2 39	.10	4.29	......	......	.07	1.13
Iron $Fe O$	......	......	......	1.92	2.50	......	......
Lime $Ca O$	.55	......	......	.14	Trace.	.16	1.17
Magnesia $Mg O$	.25	......	......	.18	......	.10	.21
Soda $Na_2 O$	.58	......	......	......	Trace. }	.12 (Soda and Potash)	.09 (Soda and Potash)
Potash $K_2 O$	.70	......	......	.18	Trace. }		
Sulphurous Acid	......	......	4.16	......	......	......	......
Phosphorous $P_2 O_5$	......	......	......	.06	......	......	......
Hygroscopic water	2 98 }	2.32 (Hygroscopic and Combined water)	9.69 (Hygroscopic and Combined water)	2.18	1.45 }	14.05 (Hygroscopic and Combined water and Organic matter)	9 71 (Hygroscopic and Combined water and Organic matter)
Combined water	5.59 }			7.10	11.05 }		
Organic matter	......	......	......	.58	...... }		
Total	100.11	97.97	99.96	99.66	98 86	100.00	100.00

I. Clay from Crill mill site; G. E. Patrick, analyst. Iron Oxide calculated as $Fe_2 O_3$.

II. Van Meter, Iowa; W. S. Robinson, analyst.

III. Van Meter, Iowa; W. S. Robinson, analyst.

IV. Stourbridge, England; C. Tookey, analyst (Percy, Met. Fuels, p. 98).

V. Savanas (Ardèche) France; Salvétat, analyst (Percy, Met. Fuels, p. 101)

VI. Mt. Savage, Md. (Tables of analyses of clays, Alfred Crossley, p. 20.)

VII. St. Louis, Mo. (Crossley.)

The Van Meter clays are the ones used by the Platt Pressed and Fire Brick Co., in the manufacture of standard fire brick. The Stourbridge and Mt. Savage clays are famous for the fire brick made from them, and the Savanas clay is used for crucibles in which cast steel is melted, at St. Etienne. For all refractory purposes it is important that the clay be as free as possible from the alkalis and other fluxing agents. The Crill mill clay contains small amounts of each of these substances, but their total is not greater than the total of several clays of excellent repute, and no one element is present to marked excess. To a certain extent, it seems that the fluxing agents counteract each other, so that the amounts found in this case do not necessarily injure the clay very greatly. With proper care in treatment, it should be possible to make a very good grade of fire brick—one amply refractory for all ordinary demands. By very especial care the clay might even be used in the manufacture of refractory materials of still higher grade.

In the Benton beds, not far above the fire clay, one finds abundant clay shale suitable for hard brick and pavers. The fire clay itself is too low in fluxing materials to allow it to be made up into paving brick economically. The Benton shales are not so pure and are accordingly better adapted to this work. A mixture of the two would probably give excellent results. For making sewer pipe, loess could be mixed with the clays to increase the percentage of silica.

Aside from the Cretaceous clays just described, and which outcrop only in the southwestern portion of the county, the loess affords the most important source of material for the brick industry. It is abundant, widely distributed, easily manipulated and yields an excellent brick. It can be made up by hand, worked as a stiff mud, or manufactured by the dry-press process. The latter seems to be the best treatment from the phase of the loess found here. It is light, open and porous and, when put through the dry-press, should yield a hard, smooth-surfaced brick. However moulded, it may be burned to an excellent, and even cherry, color at moderate heat. There is probably no widely distributed material which can be so cheaply manipulated, and is capable of yielding such an excellent finish brick, as the loess. In Plymouth county, the material is of as good quality as any found in the state. The only restrictions on its use are the necessity of importing fuel and the presence in much of it of lime balls. The latter can usually be avoided in digging.

The Le Mars Brick and Tile Co. have works in the northern part of that town. The present company has only been in operation since 1892, though brick had been made at Le Mars before that date by other firms. The pit shows a thickness of about eight feet of loess, somewhat plastic but rather friable, overlying certain sand and gravel beds also worked by the company. In color the clay is in the main buff, but it shows horizontal bandings of yellow and blue drab. It carries a few lime balls which are usually in distinct bands. There are also occasional thin streaks of fine gravel well up into the loess. The clay is tempered in a pit, moulded on a Martin horse-power machine, dried under sheds on pallets and burned in up-draft kilns. They are of good weight and color and meet a ready sale.

At present this the only plant operating in Plymouth county. At Sioux City, to the south, there are extensive works, using both the loess and the Cretaceous clays and in Sioux county, to the north, there are brick works at Orange City and Hawarden. The works at the latter point use the Pierre shale to good effect. They have been recently burned, but will doubtless be rebuilt.

Cement.

The manufacture of Portland cement is a rapidly expanding industry. In 1897 the production has been estimated* at 2,100,000 barrels with a value of $3,570,000. The production and imports for the preceding four years as given in the Eighteenth Annual Report of the United States Geological Survey are noted below.

* Eng. Min. Jour., p. 3. Jan. 1, 1898.

TABLE I.

	1891. BARRELS.	1893. BARRELS.	1895. BARRELS	1896. BARRELS.
Production in the United States	454,813	590,652	990,324	1,543,023
Imports	2,988,313	2,674,149	2,997,395	2,989,597
Total	3,443,126	3,264,801	3,987,719	4,532,620
Exports	....	14,276	83,682	85,486
Total consumption	3,443,126	3,250,525	3,904,087	4,447,134
Percentage of total consumption produced in the United States	13.2	18.2	25.3	34.7

It will be noted that while the consumption has in that time increased about thirty per cent the imports have remained stationary. The large consumption has been met by domestic manufacturing. New factories have been built and old ones enlarged until practically a new industry has been created. In 1896 Portland cement was made in eleven states, as is shown by the table given below.

PRODUCTION OF PORTLAND CEMENT IN 1896.*

STATE.	NO. OF WORKS.	BARRELS.	VALUE NOT INCLUDING PACKAGES.
California	1	9,000	$ 18,000
South Dakota	1	24,000	48,000
Illinois	1	3,000	5,250
Indiana	1	9,000	15,750
Michigan	1	4,000	7,000
New York	7	260,787	443,175
New Jersey	2	247,100	370,650
Ohio	4	153,082	267,892
Pennsylvania	7	825,054	1,224,294
Texas	1	8,000	24,000
Utah	....	....	....
Total	26	1,543,023	$ 2,424,011

In addition to the plants in operation at that time there are several others since built or now building. This remarkable growth is the result of a largely increased demand. Not only is cement being applied to a large number of new uses but larger quantities are being used in old lines of work. For

*Eighteenth Ann. Rept. U. S. Geol. Surv., pt. v, p. 1170.

example, while it has long been extensively used in the manufacture of concrete, there is now a much large amount of concrete used. In our own state the recent wide use of brick paving has absorbed a large amount of cement; concrete is also being more and more used in river improvement work for locks and dams, and the railways are using large amounts far making culverts and bridge abutments. This great expansion of the cement industry in the face of the general business depression of recent years has been a very striking event. If the erection of new mills continues at the present rate, production must soon inevitably catch up with the demand and prices be lowered. As will be seen from the figures already given there is still room for a considerable expansion so long as so large an amount of foreign cement is absorbed by the local market. It is now conceded that American cements are fully the equal of any foreign brand and in the local market they must always have the advantages of not having to undergo a long sea voyage. In the future when competition becomes keen, the mills which are best equipped or best located, or those which have materials most cheaply prepared, will be the ones to command the trade.

In the manufacture of cements the essentials are calcium, silica and alumina. The two latter are usually obtained from clay. The former may be derived from limestone, chalk or marl. As a matter of fact a large amount of cement is made from argillaceous limestone which furnishes the calcium and a portion of the alumina and silica. In some foreign mills a very pure limestone is used, but in general American manufacturers have prefered to handle softer materials so as to avoid the expense of crushing and grinding. Of these soft materials both chalk and marl have been used and each has its advantages and disadvantages. The former is in use at the Yankton works not far west of Plymouth county and is also the basis for the cement made at White Cliffs, Ark. Marl has been used principally in New Jersey, Ohio and Michigan. While marls similar to that in use in the latter states is known to occur in Iowa, so far no beds have been located which are extensive enough to warrant the establishment of a cement mill. The chalk then seems to be the most available material and the most extensive exposures of chalk occur along the Big Sioux, mainly in Plymouth county. The distribution of the beds and sections showing their thickness have already been given. It is obvious that the quantity present is sufficient to warrant investment. It remains to examine the quality and to inquire as to the trade conditions.

Messrs. S. B. and W. B. Newberry, as the result of a series of careful experiments, summarize the chemical features of cement making as follows.*

"The conclusions to which the writers are led by the above experiments may be briefly stated as follows:

"1. The essential constituents of Portland cement are tri-calcium silicate with varying proportions of di-calcium aluminate. This composition may therefore be expressed by the formula

$$X\,(3\,CaO\,SiO_2) + Y\,(2\,CaO\,Al_2\,O_3).$$

"From this formula it may be calculated that the correct proportion of lime, by weight, in Portland cement, is 2.8 times the silica plus 1.1 times the alumina.

"2. Iron oxide combines with lime at a high heat, and acts like alumina in promoting the combination of silica and lime. For practical purposes, however, the presence of iron oxide in a clay need not be considered in calculating the proportion of lime required.

"3. Alkalies, so far as indicated by the behavior of soda, are of no value in promoting the combination of lime and silica, and probably play no part in the formation of cement.

"4. Magnesia, though possessing marked hydraulic properties when ignited alone, yields no hydraulic products when heated with silica, alumina or clay, and probably plays no part in the formation of cement. It is incapable of replacing

*Cement and Eng. News., vol. IV, No 1, p. 5. 1898 lime in cement mixtures, the composition of which should be calculated on the basis of the lime only, without regard to the magnesia present."

Using the formula given X (3 CaO Si O_2) + Y (2 CaO Al_2O_3) they made up and tested cements as indicated below,* from which the theoretical composition of pure cement may be seen.

FORMULA X (3 CaO SiO) + Y (2 CaO Al O).

	R. Lime to Silicate.	CaO.	SiO_2.	Al_2O_3.	PAT TEST.	HOT TEST.	Tensile str'ngth ¼ sq. inch in section.	
							7 days.	28 days.
Silicate ....95.8 / Aluminate. 4.2	2.67	72.79	25.21	2.00	Set hard, sound, on glass.	Sound, off glass, hard.	154	173
Silicate ...91.6 / Aluminate .4	2.57	71.90	24.10	4.00	Set hard, sound, on glass.	Sound, off glass, hard.	148	227
Silicate ....85.3 / Aluminate 14.7	2.39	70.55	22.45	7.00	Set hard, sound, off glass.	Sound, on glass, hard.	180	205
Silicate ....74.8 / Aluminate 25.2	2.15	68.31	19.69	12.00	Set quick, sound, off glass.	Sound, on glass, hard.	105	84

The actual compostion of the leading cements on the market is given below† the figures being taken from the paper quoted.

CALCIUM SILICATES.

FORMULA.	R. CaO to Silica.	CaO.	SiO_2.	PAT TEST.	HOT TEST.
2 Ca SiO	1.85	65.11	34.89	Set hard, hard 7 days, hard 6 weeks.	Sound, on glass, hard.
2½ CaO SiO_2	2.33	70.00	30.00	Set soft, fairly hard 7 days, hard 6 weeks.	Sound, on glass, hard.
3 CaO SiO_2	2.80	73.68	26.32	Set soft, fairly hard 7 days, hard 6 weeks.	Sound, on glass, hard.
3½ CaO SiO_2	3.27	76.56	23.44	Cracked soft, 1 day, hard 6 weeks.	Sound, on glass, hard.

An analysis made by Mr. W. B. Newberry of the chalk as exposed at Hawarden is given below.

* Cement and Eng. News, vol. III, No. 6, p. 85. 1897.
† Cement and Eng. News, vol. III, No. 5, p. 76. 1897.

Insoluble	21.95
Silica	.75
Iron and Alumina (oxides)	6.68
Calcium carbonate	64.30
Magnesium carbonate	5.38
Total	99.03

This shows that the material while in other regards suitable for use, is too low in calcium carbonate. To manufacture cement from it, it would be necessary to mix in purer material. Partial analyses of material from the region, made for the Survey by Dr. J. B. Weems, give the following results.

	I.	II.
Calcium carbonate	83.70	94.39
Magnesium carbonate	2.48	.70
Water	.08	.06

I. Chalk rock from old quarries on Big Sioux river south of Westfield.
II. Chalk rock from Deep creek northeast of Le Mars, Sw. Sec. 2, American Tp.

These samples show an abundance of calcium carbonate and suitable freedom from magnesia. While some of the material would probably not run so pure, the samples analyzed stand for a very large portion of it and indicate that by suitable selection an excellent cement mixture could be made up. Chemically then the material is suitable.

In its physical character the chalk rock is well adapted to the work. It is homogeneous, easily quarried and easily crushed. It could be manipulated by simple machinery as has been proven at Yankton. It is well adapted to the ordinary wet process. Suitable clay is found near the chalk both at Le Mars and Westfield. Railway facilities at Le Mars are good and the Westfield deposits could be connected with the Chicago, Milwaukee & St. Paul railway by an inexpensive track along the river bottom on an old grade still in fair preservation. In the matter of fuel the plant would be at the disadvantage of having to ship in its coal but with the new Arlborg kiln as adapted to this work fuel at $2 per ton amounts to only five cents per barrel of cement.*

*Newberry: Cement and Eng. News, p. 53. Oct, 1897; Eighteenth Ann. Rept. U. S. Geol. Surv.

To summarize it may be stated that the cement industry is rapidly expanding and is meeting a growing market. There are opportunities for the manufacture of Portland cement near Le Mars and Westfield; each site would have the advantage of excellent material easily worked, and of ready railway connection. The plant would be prepared to supply an important district with no neighboring competition except from Yankton. With the exception of the fuel cost, which is relatively unimportant, the plant would be well prepared to compete with eastern factories.

In a choice between the two sites it should be remembered that the Westfield locality would offer the advantages of certain abundance of material, and would allow of the simultaneous opening and use of an excellent fire clay. It would require a longer railway spur. At Le Mars it is uncertain, in the absence of test pits, that the chalk beds are extensive enough to warrant investment. The site would, however, have the advantage of ready competition in railway connection. If either site is to be utilized it should be done without delay so that the new mill may be established before the impending period of close competition. The mill should also be built with a view of the greater economy in operation, rather than in first cost, and should be placed in experienced hands; otherwise it would probably soon prove to be a bad investment.

Lime.

In the early days the chalk rock was burned at a number of localities for lime, but in recent years the magnesian limes of the eastern portion of the state and elsewhere have driven the local product out of the market. As is shown by the analyses already given the chalk rock would only yield a non-magnesian or white lime. This is more difficult to handle and to use, and is less satisfactory than the darker colored magnesian limes, and it is doubtful whether a local plant could be made to pay. There is, however, in some quarters a large market for the white limes and the matter would be worthy of investigation, particularly in event of the establishment of cement or other works for utilizing the chalk in other ways.

Coal.

At various times in the past prospecting for coal has been undertaken within the limits of the county. The active work has been confined to two localities, one on the Big Sioux river near Westfield, and the other at Le Mars. Some diamond drill work has also been done not far north of Chatsworth, in Sioux county. At the Westfield locality, more specifically at the Crill mill site, the lignite vein already mentioned outcrops near the water level. In 1894 the Plymouth Mining Co. undertook to explore this vein, and a drift was driven in at the water's edge. It was found that, while the bed thickened somewhat under the hill, the quality remained poor, and that the amount of clay mixed with the lignite was so great as to render the whole of no value. A shaft sunk to the vein back some distance from the river confirmed the opinion derived from the bed as shown in the drift, and the work was wisely abandoned.

In the course of the drilling between Chatsworth and Hawarden a number of thin veins of lignite were developed, but nothing which in quality or extent would warrant investment. These results are particularly trustworthy, as the work was carried on with the best machinery and under the direction of experienced and reliable men. They fully confirmed the conclusions derived from a geological study of the region that the lignite veins of the region are valueless, and that the Cretaceous will, in this state, never be an important coal producer.

The question whether underlying the Cretaceous there may be outlying pockets of coal measures involves some broader questions. Between the close of the Carboniferous and the opening of the Cretaceous, there was a long period in which the Iowa was a land surface and was exposed to vigorous erosion. In this period broad areas of coal measures were undoubtedly cut to pieces and the material carried away by the streams. In eastern Iowa there are outliers of coal measures which are now separated from the main field by wide stretches of barren country. The connecting strata were doubtless cut away, in part, before the Cretaceous, and it seems probable that if from northwestern Iowa the overlying drift and Cretaceous beds could be cleared away a similar state of affairs would be found. It is by no means certain that when the coal measures were being deposited the sea extended over much of northwestern Iowa, and it is well known the coal is not co-extensive with the coal measures. In view of these facts the probability of striking valuable beds of coal in the region is seen to be very slight.

Several deep holes have been put down in the region. At Sioux City, Ponca, Neb., Hull, Sanborn and Cherokee, wells or exploratory holes have been sunk far below the level of any possible coal with negative results. At Le Mars, three holes, of which we have complete or partial records, have been put down. The drillings from one of these was examined by Todd.* The second well, so far as a record of it is obtainable, confirms the first. The two apparently indicate that Cretaceous strata of the usual character continue down to the underlying gneiss. It would not be impossible, however, that some of the beds referred to the Cretaceous should really belong to the coal measures. As Norton suggests, however, the former hypothesis finds support in the records of the Sanborn and Cherokee wells.

The third drill hole was put down southeast of the town (Tp. 92 N., R. XLV W., Sec. 15), by C. P. Woodward, who has furnished the following careful record.

*Proc. Iowa Acad. Sci., vol. I, pt. ii, p. 14; see also Norton, Iowa Geol. Surv., vol. VI, pp. 232-233. 1897.

		FEET THICKNESS.	DEPTH.
59.	Drift	25	25
58.	Bluish-black clay, with bituminous matter and gypsum	25	50
57.	Bituminous matter and gypsum	10	60
56.	Soapstone and clay, organic matter, colored by iron oxide and carbonate of lime and magnesia	19	79
55.	Bed rock, very hard, ferruginous sandstone, slightly calcareous	$3\frac{2}{3}$	83
54.	Calcareous sandstone, iron oxide, first seam of lignite, one inch; also sulphate of magnesia	$2\frac{1}{2}$	$85\frac{1}{2}$
53.	Arenaceous, chalky, and calcareous stone, with marly partings containing nearly pure calcium carbonate	$7\frac{1}{2}$	93
52.	Calcareous marl	1	94
51.	Calcareous fragments	1	95
50.	Slate, rotten, bituminous, calcareous	6	101
49.	Slate, slightly calcareous	11	112
48.	Shale, calcareous	1	113
47.	Slate, rotten, bituminous, and shale	12	125
46.	Soapstone and slate	6	131
45.	Shale, calcareous	1	132
44.	Shale, calcareous and siliceous, mineral-bearing	5	137
43.	Shale	8	145
42.	Shale, very hard	1	146
41.	Limestone, in bands, hard, bituminous	12	158
40.	Slate, bituminous, and shale, with streaks of coal and limestone	4	162
39.	Shale, hard slate and shale, wind veins blowing sand out of top of well at 175 feet	13	175
38.	Slate and shale, with limestone bands and openings	4	179
37.	Conglomerate, hard	2	181
36.	Sandstone, hard, ferruginous, calcareous, with slate streaks	6	187
35.	Sandstone, reddish-brown, ferruginous	8	195
34.	Rotten siliceous rocks, slate and blackjack	6	201
33.	Slate and fire clay, with streaks of hard coal	4	205
32.	Sandstone, micaceous, with streaks of fine clay	6	211
31.	Fire clay and slate	4	215
30.	Sandstone, hard, micaceous	5	220
29.	Slate, bituminous	2	222

		FEET THICKNESS.	DEPTH.
28.	Upper coal basin	2½	224½
27.	Fire clay, 6 feet; sandstone, 1 foot	1½	226
26.	Sandstone, dark, organic	5	231
25.	Shale, bituminous	3⅓	234¾
24.	Coal	1¼	236
23.	Fire clay, fine coal	1	237
22.	Soapstone and slate, limestone and coal streaks	5	242
21.	Shale, arenaceous, coal in streaks	⅔	242⅔
20.	Black oxide of iron (magnetic) hard, solid.	6	248⅔
19.	Same with soapstone	6	252⅔
18.	Gypsum and soapstone.	6	258⅔
17.	Soapstone, hard ferruginous, with gypsum.	4½	263⅙
16.	Coal and slate	½	263⅔
15.	Slate and fire clay, pyrite	4⅓	268
14.	Soapstone	15	283
13.	Chert	½	283½
12.	Soapstone	6½	300
11.	Slate, bituminous, with pyrite	6	306
10.	Slate, bituminous, siliceous with pyrite	9	315
9.	Slate, fine-grained with pyrite	8	323
8.	Sandstone, brown, ferruginous, with streaks of coal and slate	11	334
7.	Sandstone, brown, ferruginous with heavy spar	....	....
6.	Shales, quartz crystals	6	340
5.	Shale, ferruginous, calcareous	10	350
4.	Quartz rock and spar	14	364
3.	Sandstone, ferruginous, with fluor spar	6	370
2.	Shales, siliceous, with streaks of carbon	6	376
1.	Coal, solid vein	5	381

This work was done with a churn drill, but seems to have been very carefully executed. The coal drillings do not differ in appearance from those obtained in ordinary work at various points in the Iowa field. Proximate analyses showed that the percentages of fixed carbon, ash and volatile matter, were not higher than usual with Iowa coal, and would, to that extent, indicate that the coal was Carboniferous, rather than Cretaceous. The assemblage of strata with the coal, is such as might come from either formation, so that while there is no decisive evidence, it is quite possible that the drill here tapped a coal measure outlier.

If this be true, it is quite probable that the coal is valuable. The matter can only be authoritatively determined, however, by further drill holes, so placed as to outline the limits of the bed.

Water Supply.

The streams of Plymouth county furnish a large amount of water which is available for stock and steam purposes. The area enjoys a good annual rainfall. At Smithland, not far south of the county limits, observations show the average rainfall for nine years to have been 24.45 inches.* Owing to the fact that the surface is covered with loess, the larger portion of this precipitation becomes available for agricultural purposes, and droughts are infrequent and slight.

The great thickness and wide variety in composition of the surface formations, makes it usually easy to obtain a good well at slight expense. The Dakota sandstone, which farther west affords such an abundant supply of artesian water, underlies the county and apparently constitutes largely the supply of ground water. Artesian wells are, however, the exception, though they are not unknown. In general the water does not rise high enough to overflow. At Oyens, in a well 190 feet deep, the water comes up over 100 feet. It is of good quality and is abundant in quantity. The fact that the Missouri and the Big Sioux have cut down deep into the Dakota, prevents it from being so important a source of water supplies as farther west. Much of the water which it carries is drained out by these streams and their tributaries.

Soils.

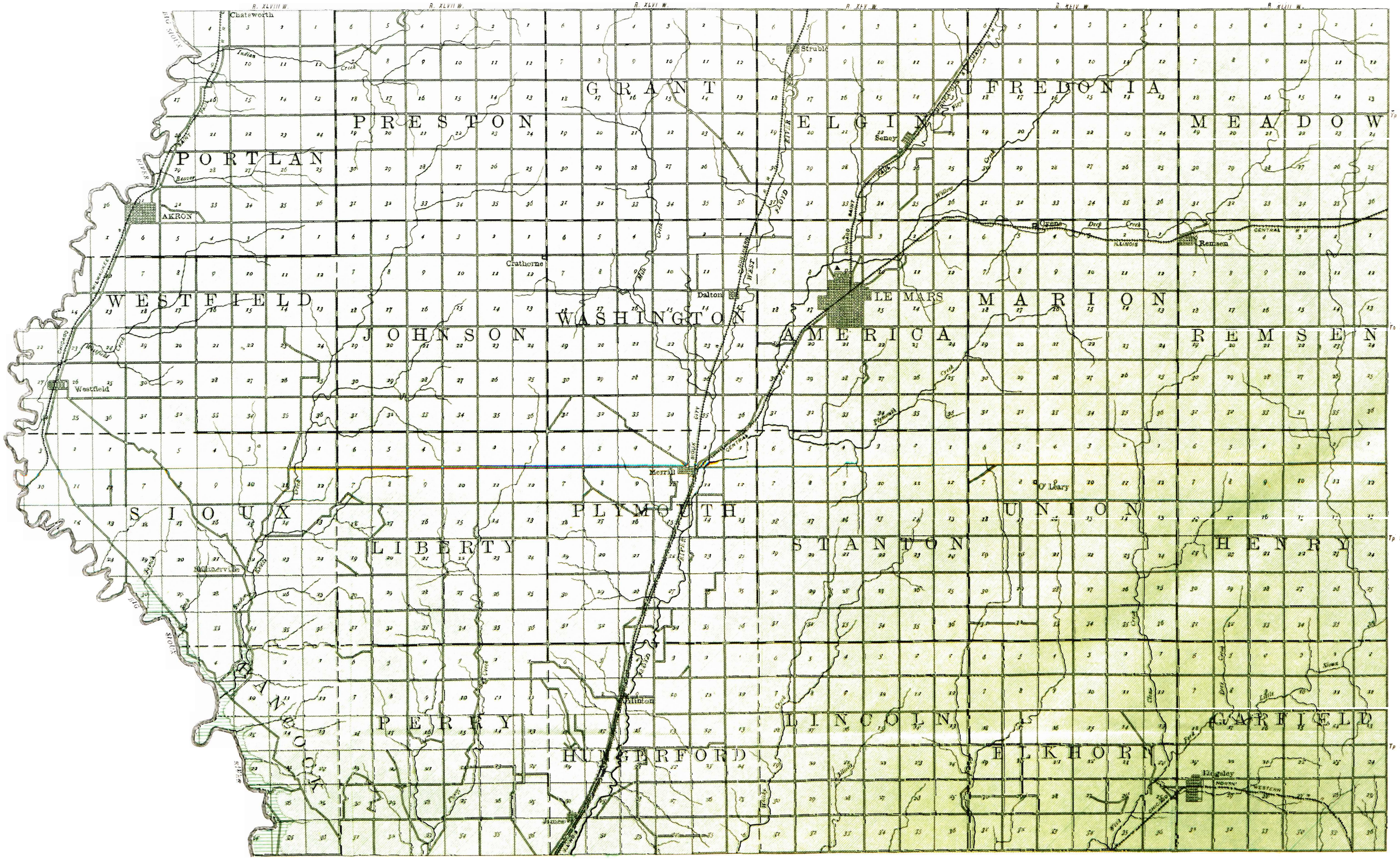
Plymouth county is essentially an agricultural county. Its wide, gently rolling prairies are closely cultivated. The loess, which forms the surface formation, affords a soil of great fertility which is easily cultivated. Over most of the county there are no stumps, stone or other hindrances to cultivation, and, except along the western border in the immediate

*Ann. Rept. Iowa Weather Serv., 1896, p. 55.

vicinity of the streams, the ground is not broken enough to interfere with farming operations. As has already been suggested, the texture of the soil is such as to prevent it from suffering much in dry seasons, and yet it has good underdrainage.

ACKNOWLEDGMENTS.

The Survey has received much assistance in the course of its work from various parties, both within and without the county. Particular obligations are felt to Judge G. W. Wakefield, Hon. Ed. M. Chassell, Mr. W. J. Wermli and Mr. Gus Pech for advice and assistance in the field work, to Mr. S. B. Newberry, of Sandusky, Ohio, for tests of cement material, and Professors Calvin, Chamberlin, Salisbury and Todd for assistance in the study of the Pleistocene. To these and to the many others who have freely given their time and services to the work, the author's most grateful acknowledgments are tendered.



IOWA GEOLOGICAL SURVEY

GEOLOGICAL MAP OF PLYMOUTH COUNTY, IOWA.

BY

H. F. BAIN

1898.

Scale 1:125000

LEGEND

GEOLOGICAL FORMATIONS

COLORADO

DAKOTA

INDUSTRIES

CLAY WORKS ▲

IOWA LITHO CO DES MOINES

DRAWN BY F. C. TATE