GEOLOGY OF CRAWFORD COUNTY

BY

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Introductory

Location and Area.—Crawford county lies immediately west of the Mississippi-Missouri divide and is separated from Missouri river by only one county—Monona—which forms its western boundary. It lies in the middle east-west tier of counties and is therefore practically equidistant from the north and south boundaries of the state. Ida and Sac counties form the northern border of Crawford, Carroll bounds it on the east and on the south are Shelby and Harrison counties.

When Doctor White was making his survey of western Iowa in the late sixties he stated that Crawford county comprised sixteen congressional townships and had an area of 576 square miles. The map which accompanies his report, however, shows the county as having the same area as at present, twenty congressional townsips. Each of these townships is conterminous with a civil township and the area embraced within the county is 720 square miles. The county embraces townships 82 to 85 north and ranges 37 to 41 west.

History.[1]—In 1830 the area of Crawford county was first ceded to the United States by treaty with the Sacs and Foxes and other Indian tribes. It remained in an unorganized condition, however, until 1851, when by act of the legislature its boundaries were defined and it was named in honor of William Harris Crawford, at one time senator from Georgia, and Secretary of the Treasury of the United States. The county was then attached to Shelby county. It became an independent organization in 1855, the county seat being located at Denison, a town founded by the Providence Western Land Company, of Providence, Rhode Island, and named in honor of its agent, J. W. Denison. The county then contained sixteen government townships. In 1865, by joint action, four townships were detached from Monona county and added to the west boundary of Crawford county,

[1] The outline of Crawford county history was kindly furnished by Mr. F. W. Meyers, formerly of Denison, who has written a comprehensive history of the county.

since which time the county lines have remained unchanged. The first permanent settlement was made in 1849 by Cornelius Dunham and Franklin Prentice, at Dunham's Grove, six miles east of Denison. The next settlement was made by Jesse Mason at Mason's Grove, in the vicinity of Deloit. Among the earliest settlers were Benjamin Dobson, Thomas Dobson, John R. Bassett, the first county judge, J. W. Denison, H. C. Laub, Morris McHenry, and S. E. Dow, after whom the town of Dow City is named. The first telegraph line was in 1866 and this was followed in 1867 by the building of the Chicago & North Western railroad. The first newspaper was the Boyer Valley Record, published in 1861. It was succeeded in 1867 by the Denison Review. Prominent names in Crawford county's history are Governor Leslie M. Shaw, Congressman J. P. Conner, Colonel Alonzo Abernethy, J. Fred Meyers, W. A. McHenry, Carl F. Kuehnle, J. B. Romans, Charles Bullock and P. E. C. Lally.

Previous Geological Work.—The earliest geological studies in this area were carried on by Orestes H. St. John in 1867, under the direction of Doctor Charles A. White, at that time State Geologist of Iowa. St. John was instructed to make a reconnoissance of that part of the state embraced within the fourth, fifth and sixth tiers of counties lying between Des Moines and Missouri rivers and the prosecution of his work necessarily led him over Crawford county. The results of his study were transmitted to his chief and published in the Second Annual Report of Progress of the State Geologist for 1867 under the title "Geology of the Middle Region of Western Iowa."[2] Frequent mention is made of Crawford county and its various natural features—streams, topography, geological formations and forests. The loess of western Iowa was described by St. John, as well as by other workers of his day, under the name of the Bluff formation, an appelation derived from the great development of the formation on the Missouri bluffs. St. John also recognized the presence of the drift, although there is no evidence that he distinguished more than one stage. The evidence of the lacustrine origin of the "Bluff" was considered conclusive. On this point St. John says:[3] "The fine nature of the material which

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2 First and Second Ann. Rept. Progress by State Geologist, etc., pp. 191-201, Des Moines, 1868.
3 Op. cit.: p. 193.

comprises the bluff seems to furnish conclusive evidence of its lacustrine origin. On the other hand, the coarse materials which enter so largely into the composition of the drift, were deposited at the bottom of the great fresh-water sea at the close of the glacial period." St. John makes particular mention of the gravel deposits at and near Denison, which, he states, were utilized for making concrete brick, and some of which were sufficiently indurated to be used for building up rough walls. He also recognizes and comments upon the sharp distinction between the mature erosional type of topography so typically developed in Crawford county and the youthful constructional phase presented in Sac county, with its absence of the "Bluff" and its abundance of surface bowlders and drift ridges.

In the final report of the State Geologist[4] White describes the rivers which drain Crawford county, although the county is not mentioned by name. The Drift and the Bluff deposit also are discussed in this volume.

In the same report[5] St. John devotes several pages of his discussion of the "Geology of the Middle Region of Western Iowa and Other Counties" to a résumé of the surface features and geology of Crawford county. He describes briefly the streams, surface configuration, soils and forests of the county and speaks of the presence of the Drift, the gravels and the Bluff Formation. The absence of exposures of the indurated rocks underlying these loose deposits is noted and the author wisely remarks that: "Of the coal-measure series, even if it does underlie the area embraced in Crawford county, the productive or Lower formation probably lies at so great a depth beneath the surface as to render its development for the present impracticable." The accuracy of St. John's observations has been abundantly proved by subsequent developments.

St. John also urges the advisability of tree planting to provide fuel. The cessation of prairie fires since his day makes the carrying out of his advice especially easy and its wisdom will not be questioned.

The earlier workers in Iowa—Owen and Hall—did not extend their labors to this part of the state, nor have the investigators

4 Geology of Iowa, C. A. White, vol. I, pp. 48-51; 1870.
5 Idem, vol. II, pp. 168-171.

of the present Survey until recently attacked the problems of Crawford county, since the field offers but little of special interest to the student of economic problems.

Several of the bordering counties have received attention at the hand of the workers on the Iowa Geological Survey. Carroll county was surveyed by Bain,[6] Sac and Ida counties by Macbride,[7] Woodbury by Bain,[8] and Shimek a few years ago discussed Harrison and Monona counties.[9] Shelby and Audubon counties are still under investigation.

Kay has described the splendid exposures of glacial drift along the main line of the Chicago, Milwaukee and St. Paul Railway as these are located in this county. His descriptions are found in a paper entitled "Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County, Iowa," which appears in volume XXVI of these reports.

Calvin and Shimek described various deposits of gravels which they considered to be of Aftonian age and they discussed the abundant mammalian remains found therein. Some of these remains came from the gravel pits near Denison. The papers of Calvin and Shimek are found in Volumes XX and XXI of the Bulletins of the Geological Society of America.

6 H. F. Bain, Iowa Geol. Survey, vol. IX, p. 51.
7 T. H. Macbride, Op. cit., vol. XVI, p. 509.
8 H. F. Bain, Op. cit., vol. V, p. 241.
9 B. Shimek, Op. cit., vol. XX, p. 271.

PHYSIOGRAPHY

Topography

Topographically Crawford county forms part of a great upland plain which includes all of western Iowa. This statement needs qualification insofar as the main drainage courses are concerned, since they have assumed the form of flat bottom lands. But these are relatively an unimportant topographic feature and hence the first statement practically covers the conditions. This upland plain, as here defined, is drained into Missouri river as distinguished from that part of the Iowa prairies which slopes toward and whose run-off finds its way into the Mississippi. The dividing line between these two drainage areas—the Missouri-Mississippi watershed—extends across western Carroll county within two or three miles of the Crawford-Carroll boundary as far south as the southern boundary of Arcadia township whence it swings southeastwardly to the middle of the south county line. The towns of Arcadia and Templeton are situated on this divide and the rains which fall in their immediate vicinity find their way eastward to the Mississippi or westward to the Missouri according as they fall to the east or west of these towns.

The Height of Land.—Under these conditions we should expect to find a more or less uniform slope from the divide across Crawford county to the west and southwest. And this is in part true as will be seen from an inspection of the list of altitudes for the county. Yet we shall scarcely be prepared for the discovery that there are within the county many points which have an elevation considerably above that of the divide as that feature is developed in Carroll county and indeed above the surface of the divide for some distance north or south of Carroll county. But that this is the case may be shown by comparing a series of elevations along the watershed with a similar series to the west. Thus the former series from north to south gives, in feet above sea level: Alta, 1514; two miles east of Early, 1388; two miles west of Lake View, 1370; uplands north of Arcadia, 1476; two miles southwest of Halburn, 1414; Templeton, 1431; Adair, 1398 at the station, increased to nearly 1500 feet on the uplands. Between Templeton and Adair no figures are available but it is not likely that the elevation is any higher than that of Adair since the town crowns the summit of the watershed and erosion has been very active along the flanks of the divide in Guthrie and Audubon counties.

West of Alta the highest point on the Illinois Central railroad is 1459 feet at Cleghorn. The highest land here seems to coincide nearly with the divide. West of Early on the Chicago & North Western railway we have: one mile east of Schaller, 1440, and one mile west of Holstein, 1456. The uplands around Schaller are somewhat higher than the highest point on the railroad. Holstein is built on the highest land in the region, as was noted by Macbride.[10] He also described a series of hills representing this plateau which extend southeastwardly across Ida and Sac counties and into Carroll county. It is also doubtless represented in Crawford by the high upland ridges and divides of the eastern and central parts.

Continuing southward, however, we find that the highlands north of Ida Grove reach an elevation of 1500 feet, while the divide between Maple and Soldier rivers rises to nearly the same level. Further east along the extension of this same ridge the prairie immediately east of Odebolt rises to 1415 feet as compared with the 1370 feet west of Lake View on the main divide, which here also separates the waters of the Boyer from those of North Raccoon river and its tributaries. Whereas the high points of northwest Carroll rise to 1476 feet those to the west in Crawford rise to 1500 feet in central Jackson township and to greater heights in Morgan township a mile or two west of Schleswig. A number of points in Crawford county must approach or reach elevations of fifteen hundred feet, such for instance as the uplands in central Hays township, those in the northeast part of Washington township, in southwest Paradise township, and in Willow township two miles south of Ute. The divide between Botna and Aspinwall reaches about fifteen hundred feet, about fifty feet higher than Templeton. Around Manning the hills

10 T. H. Macbride, Geology of Sac and Ida Counties: Iowa Geol. Survey, vol. XVI, pp. 514, 515.

rise 175 feet above West Nishnabotna river which here flows at about 1320 feet above sea level.

If we wish to carry this study to the northern part of the state we find the following altitudes north of the Illinois Central. Along the Chicago & North Western: Laurens, 1313 feet; Marathon, 1392—where the road crosses the divide; Sioux Rapids, 1278, in the valley of Little Sioux river; a mile west of Sutherland, 1480; a mile north of Gaza, 1520; Granville, 1447; Orange City, 1411. Along the Chicago, Milwaukee & Saint Paul: Crippen, 1260 feet; Ruthven, 1428—at the divide; Hartley, 1456; Sanborn, 1547; Sheldon, 1409; Perkins, 1455; near Big Sioux river, 1463. If we follow the line of the Chicago, Rock Island & Pacific from Laurens to Sibley we get the following altitudes: Laurens, 1303 feet; Leverett, 1365—on the divide; Maclay, 1365; Royal, 1417; Hartley, 1465; Plessis, 1522; Melvin, 1585; Sibley, 1522. A line of altitudes across the northern tier of counties shows: Armstrong, 1249 feet; Gruver, 1311; Raleigh, 1440; Divide Spur, 1548; Spirit Lake, 1465; Lake Park, 1469; Ocheyedan Mound, about 1670; upland northeast of Sibley, about 1670; Worthington, Minnesota, 1585; Ellsworth, Minnesota, 1455; Larchwood, 1468; Granite, one mile south of, 1440; Sioux Falls, South Dakota, 1405. A north-south series of elevations near the divide runs as follows: Huntington, 1345 feet; Divide Spur, 1548; Raleigh, 1440; Terrill, 1415; Ruthven, 1432; Webb, 1368; Marathon, 1392; Rembrandt, 1332; Truesdale, 1359; Storm Lake, 1442; Alta, 1514; Early, 1388. Compare this with a similar series farther west, as follows: Sibley, 1522; Melvin, 1585; Sanborn, 1547; Primghar, 1504; Gaza, 1508; Cleghorn, 1459; Holstein, 1456; near Schleswig, about 1535; or near Schaller, 1440; near Odebolt, 1380; central Jackson township, Crawford county, about 1500 feet.

This multiplicity of figures cannot fail to show that there is a gradual increase in the elevation of the surface of northwestern Iowa from the east to a region some distance beyond the watershed whence there is a gradual decline toward the Missouri and Big Sioux. This divergence of the watershed and the region—it cannot be considered as a line—of greatest altitude does not seem to be continued northward beyond Worthington in southern Minnesota, and apparently the two come into closer coincidence toward the south where they approach the main line of the Rock Island Railway, in the latitude of Adair. There is a secondary watershed which leaves the main one near Greenfield and passes through Creston and Mount Ayr. This is higher than the main divide but it is to be noted that it *is* a watershed, that in Iowa at least, no streams cut through it, although streams do rise on both flanks. Herein it differs essentially from the high land of western and northwestern Iowa.

There are, then, two questions which call for solution. First, why should the surface continue to rise to the west of the divide instead of sloping down toward the great river to the west? This is a most anomalous condition and seems to be in direct contradiction to the law of stream divides. Second, why have the larger streams cut through this high land and why do they now head on lower ground to the east, near the dividing line between the two major river systems? Why should they not all, as indeed some of them do, take their rise on the western slopes of this highland and thus place the divide where it seems to belong? This is in part a restatement of the first question, since the answer to it involves the location of the divide. But there are other elements in the question which make it advantageous to discuss it apart from the first.

Let it be understood that the problem is not complicated by warpings or other disturbances of the underlying strata. The formation immediately under the glacial drift lies essentially horizontal and rests upon the edges of an older series of rocks which dip gently to the east or southeast. Therefore the superior elevation of any point must be due to the greater thickness of either the indurated rocks or the superficial materials. It is true, of course, that there is a gradual elevation of the surface from the Mississippi across the Great Plains to the Rocky mountains. And this is without doubt one of the factors in the problem. But as will be seen later the surface of the indurated rock is at about the same elevation wherever it has been reached by wells in Crawford county, with one or two exceptions. This indicates a thickening of the overlying clays and other surface deposits in order to make up the increase in elevation. As the valley of the Missouri is approached the surface naturally slopes off to the southwest, due both to a lowering of the rock surface and to the thinning of the overlying material, probably by erosion in part. It may well have been that in Pleistocene time, when the continental ice-field covered Iowa, it left a greater thickness of detrital material along this strip of prairie extending from Osceola county to Crawford county and perhaps beyond, than was deposited either to the east or to the west. An inspection of the geological sections given in Norton's reports on the Artesian Wells of Iowa[11] will sustain this hypothesis. The answer to the first question is, then, that the greater elevation west of the divide is due very largely to an increase in thickness of the superficial deposits[12] and in lesser amount to the natural slope from the Mississippi upward toward the Rockies.

Passing to the second question, the reason for the streams taking their rise east of the "height of land" we note that along most of the region we are discussing the divide is approximately parallel with and very close to a line marking the margin between two regions of very mature and very immature drainage respectively. These will be described later as the areas of the Kansan and the Wisconsin drifts. Now the streams on the western side of this line, in the Kansan drift area, have been at work making their valleys and cutting down the hills for long, long centuries. The rivers and creeks of the Wisconsin area, on the contrary, began their work only a comparatively short time ago. Studies of these two areas in different parts of Iowa have led Doctor Kay to the conclusion that if we consider the time since the streams of the Wisconsin area began their work as unity then the age of the Kansan streams will be more than one hundred sixty times as great. In other words the streams to the west of the Wisconsin drift margin, or of the watershed, which amounts to practically the same thing, have been at work more than one hundred sixty times as long as have those to the east of these lines. Doubtless when the tributaries of Missouri river began to run they headed on the western slopes of this high ground described as extending from Osceola to Crawford counties. But all through the centuries and milleniums they have been cutting back and lengthening out by headward erosion until some of

11 W. H. Norton, Iowa Geol. Survey, vol. VI, opp. pp. 178, 202, 236. Also vol. XXI, opp. pp. 310, 458.

12 For further discussion of this point see the description of the Kansan Drift, under head of Stratigraphy.

them have worked entirely across the height of land, and those which have not yet attained this end are working toward it as fast as they can. Two continental glaciers have invaded central Iowa since these streams began their erosive action and the floods of water accompanying the melting of these glaciers may have aided somewhat in this work.

On the contrary the upper parts of Des Moines river and its tributaries have had only a short time to work and have not advanced very far toward making wide valleys or toward lengthening their courses. Probably these streams were very nearly as long immediately after the retreat of the Wisconsin glacier as they are now. Moreover the Des Moines has but a few tributaries while the Missouri has many. The area of the Wisconsin drift may be distinguished on a map by this difference in its drainage conditions.

A study of the stream gradients does not throw much light on the problem but the evidence may be reviewed briefly. Des Moines river rises in Minnesota at an elevation of about 1850 feet. The fall to the state line, 100 miles, is 600 feet or 6.00 feet per mile. Between here and Fort Dodge, 100 miles, the valley drops from 1250 to 975 feet, an average of about three feet per mile. If the sinuosities of the stream be considered the fall is between one and one-half and two feet per mile. In Humboldt county the valley gradient is increased to eight and one-half feet per mile.[13] From Fort Dodge to Des Moines the river falls in about eighty miles practically 200 feet or 2.5 feet per mile. From here to the mouth, 201 miles, the fall is 301 feet or about 1.5 feet per mile.[14]

The only tributaries of large size from the west above Des Moines are the Raccoon rivers. The North Raccoon falls from 1430 feet at Storm Lake to 780 at Des Moines, a drop of 650 feet in about 135 miles, or a gradient of 4.8 feet per mile. The Middle Coon rises near Arcadia at an altitude of about 1400 feet and falls 620 feet in its course of about 100 miles. North Coon is entirely within the Wisconsin drift area while Middle Coon is almost entirely outside this area, just along its margin.

13 Rept. Iowa State Drainage, Waterways and Conservation Commission, pp. 67-69, 123; 1910.

14 See Letter from Secretary of War, transmitting Reports on Examination and Survey of Des Moines River. 62d Congress, 3d Session, H. R., Doc. No. 1063, pp. 4, 49, 82. Ordered printed Dec. 6, 1912.

Passing to the western side of the state we find that the Big Sioux falls 300 feet in the approximately 100 miles of its course between Sioux Falls and Sioux City. The altitude of the river at Sioux Falls is about 1400 feet. Below the falls the water level will certainly be twenty-five feet less. Low water in the Missouri at Sioux City is 1076 feet. From the mouth of the Big Sioux to Council Bluffs the main river has a course of 137 miles, in which it falls only 114 feet, less than a foot per mile. Todd[15] states that in the Elk Point quadrangle, north of Sioux City, the Big Sioux has a fall of two feet per mile and the Missouri one of six inches per mile.

Rock river, the only considerable tributary of the Big Sioux, falls along the eighty-five miles of its course, from an altitude of 1850 feet at the crest of the Coteau des Prairies in Minnesota to 1180 at its mouth, an average of 7.9 feet per mile. Floyd river falls from 1550 feet to 1076 feet, an average of 6.6 feet for each of the seventy miles of its course. The Little Sioux rises at an elevation of 1500 feet and flows 185 miles to its junction with the Missouri at an elevation of 1020 feet. Its fall is about 2.55 feet per mile. The Boyer falls from 1450 feet to 980 feet in 105 miles, a fall of 4.5 feet per mile. West Nishnabotna river rises at about 1450 feet in southwestern Carroll county and reaches the Missouri 135 miles away at an elevation of 870 feet, a fall of 580 feet or 4.3 per mile. The Nodaway at its head near Adair is about 1375 feet above sea level and at its mouth is 830 feet above sea level. It falls 545 feet in 135 miles, or four feet per mile. Of these streams the Nishnabotna, the Boyer and the Little Sioux head near the divide, and have cut through and across the high land to the west of this line to take their rise on the eastern side of the ridge. Rock river system rises on the western slope of the Coteau des Prairies in southwestern Minnesota, where the highest land is coincident with the stream divide, north of Worthington. It is significant that Floyd and Maple rivers, both of whose gathering grounds are strictly limited by their neighboring systems, have not cut across the high land but still head on its western slope. Really, the divide is not a ridge but merely a sinuous

15 Todd, J. E., U.S. Geol. Survey Geol. Atlas, Elk Point folio (No. 156), South Dakota, Nebraska, Iowa, 1908.

strip on a sloping plain where the feeders of the two great river systems have their sources.

The statements given above are incorporated in the appended table.

Mississippi System.

Name	Length, miles	Elevation From	Elevation To	Fall	Gradient
		Feet	*Feet*	*Feet*	*Feet per mile*
Des Moines	100, source to state line	1850	1250	600	6.0
Des Moines	100, to Fort Dodge	1250	975	275	2.75
Des Moines	80, to Des Moines	975	778	200	2.5
Des Moines	201, to Mississippi R.	778	477	301	1.5
North Raccoon	135	1430	780	650	4.8
Middle Raccoon	100	1400	780	620	6.2
Average gradient					3.96

Missouri System.

Big Sioux	100, Sioux Falls to Sioux City	1375	1076	300	3.0
Missouri	137, Sioux City to Council Bluffs	1076	962	114	0.83
Rock	85	1850	1180	670	7.9
Floyd	70	1550	1076	474	6.6
Little Sioux	185	1500	1020	480	2.55
Boyer	105	1450	980	470	4.5
West Nishnabotna	135	1450	870	580	4.3
Nodaway	135	1375	830	545	4.0
Average gradient					4.21

The figures given above do not indicate much difference in the gradients of the streams flowing either way from the divide as these streams exist at present. It is probable that the streams emptying into the Missouri at one time headed on the western slope of the high ridge west of the present divide and that by reason of their high grades at that time they were able to cut back swiftly and thus they eventually cleft the ridge which formed the old divide and so caused the actual watershed to migrate eastward. The streams emptying into the Des Moines have not been working so long and in addition have not the cutting power given by high gradients in their upper reaches. Hence they have not been able to compete with the streams on the other side of the watershed.

Applying the problems within the limits of our own territory we find that the superior elevations of central Crawford county are due to the greater heaping up of the glacial drift here than farther east. We find also that the watershed, which doubtless once extended across this county, has been pushed farther and farther eastward until now those streams of the county which head near the divide have cut through the ridge and now rise either in the eastern townships, such as the West Fork of Nishnabotna river, or entirely beyond the limits of the county, as, for example, Boyer river. Several streams do rise on the western slope of the ridge. Some of these rise in Crawford, among them the branches of Willow creek and South and Middle Soldier rivers; others rise extraterritorially, as does the North Soldier. None of these are such large streams as the two first mentioned and while they have no doubt accomplished a large amount of erosion they have not yet been able to cut back so far across the ridge as have larger streams like the Boyer.

TOPOGRAPHIC PROVINCES

Crawford county may be divided into two topographic provinces, though these can nowhere be sharply set off one from the other. The first province extends from the east line of the county westward well into the fourth tier of townships, where it grades insensibly into the second province, which stretches across the western tier into Monona county. The first province is prevailingly a rather strongly rolling plain deeply dissected by the major streams and their tributaries. The character of the surface of this region is determined almost entirely by the action of running water on unconsolidated deposits. Nowhere have the streams cut down to solid rock and that even though they now run in some cases 300 to 350 feet below the tops of the ridges which separate the minor drainage systems. Doubtless the surface of Crawford county was once as level as is that of Greene or Calhoun counties today. But the waters of the region, acting through uncounted centuries, have so cut up this old level plain that today as one stands upon one of the high ridges that are all that remain of the former surface it seems as though there is nowhere a section of land, or indeed a quarter section, which approaches anything like flatness. Probably the area embracing a few square miles east and southeast of Schleswig is the largest surviving remnant of the original plain. See figure 37 for a view of this plain. Whether the surfaces of this and similar smaller areas actually coincide in level with the surface of the old plain is not, of course, definitely known, although it is possible that in the case of the largest ones they very nearly do so. Stream erosion has not yet reached all these surfaces, but it may be that sheet erosion and weathering have lowered the level somewhat. However, taken as a whole this province has a typical erosion topography and one that has reached a mature stage

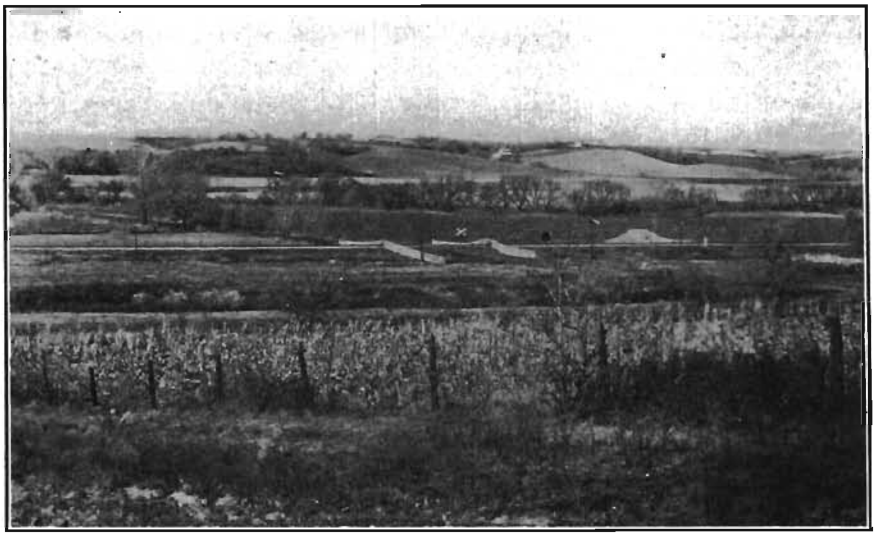

FIG. 34.—Looking west across Boyer valley above the junction with the East Boyer, in the west part of Denison.

of development. While most of the streams are still actively cutting away the land and transporting it to lower levels, yet some of them have formed flood plains of more or less importance which extend for considerable distances from their mouths. In the case of the largest stream of the county, Boyer river, this flood plain is a very well marked feature, stretching as it does entirely across the county. Figure 34 shows the valley at Denison. This stream has reached the stage where it is no longer reducing the surrounding country to any large extent but is devoting its energies chiefly to working over its valley filling. The real work of cutting down the land and carving out those forms typical of an erosion topography is being carried on by the smaller streams aided by water in sheet form. This latter is, of course, active during times of rain or melting snow and its function is a very important one, increasingly so in a land so rough as is most of our area.

Processes of Erosion.—These two agents—stream water and sheet water—have produced by their combined action the relatively short convex curves of the divides and upper hill-slopes and the long concave curves of the lower slopes and the stream valleys. These curves have been very thoroughly analyzed by Bain[16] and need be discussed only briefly here.

When sheet water runs over a surface which has any slope it tends to produce a curve which is convex since it carries away more and more material as its own volume, and hence its transporting power, increases. But when the water reaches a place where the slope is reduced the load will be deposited. This tends to build up a concave curve as most of the load is dropped where the velocity is first checked, and less and less material is carried beyond. In this way a compound curve is formed. If this agent alone be considered the curve will tend to flatten out by the cutting down of the upland and the building up of the lowland.

But every land surface shows some inequalities and the water flowing as a sheet is quickly gathered into the depressions. By this means its potential energy is concentrated and a channel is soon cut. If a channel be conceived as being originally a perfectly straight line it will soon become concave because at its mouth its velocity will be checked, both its erosive and its carrying powers will be diminished and its bed will be built up, or by continued cutting in the upper reaches a curvature will be produced. This curvature will be very gentle in the lower part of the stream but increasingly great as the source is approached, owing to several causes. At the immediate head of a stream the rills have little energy to either corrade or transport. This power increases as the volume is enlarged. Hence at some point there will be a maximum of (downward) channel cutting and this will mark the point of greatest concavity. The lengthening of a stream is accomplished by the rills at the head cutting back into

16 Bain, H. F., Relations of Wisconsin and Kansan Drift Sheets in Central Iowa, etc.; Iowa Geol. Survey, vol. VI, pp. 449-458; 1896.

and washing away the material of the surrounding land. This will tend to continue the concave curve backward. If the stream has a long course or its slope is gentle the upper reaches will have a low gradient. If, on the other hand, the streams are short or have a steep fall to their master stream the gradient at the gathering ground is correspondingly high. This is very well brought out by many of the streams of Crawford county. For example most of the streams tributary to East Boyer river have fairly gentle grades even up to their heads and the country

FIG. 35.—Deep saucer-like depressions at the headwaters of the tributaries of the Boyer, in sections 32 and 33, Goodrich township.

around them is not very rough. But when one passes over the divide between East Boyer and Boyer rivers a difference is at once observed. Boyer valley is deeper and its secondary valleys have steep courses and their heads present deep basin-like hollows carved out of the hillsides, as, for example, the one shown in figure 35. The same difference is shown in the headwaters of Paradise creek and East Soldier river, which drain Hanover township. The ravines and creeks supplying Soldier river have gentle slopes, those feeding Paradise creek are steep and the streams are swift. Soldier river drops from perhaps 1450 feet or less near Schleswig to 1160 feet at Ute, sixteen miles away, a fall of about eighteen feet per mile. Paradise creek falls from perhaps the same elevation to 1120 feet at Dow City, descending

330 feet or more in not over ten miles. The effect of these grades on the topography at the sources is easy to understand.[17]

Eastern Province.—We may proceed to the discussion of some of the details of the topography of this eastern province.

The dominating stream of this region is Boyer river. The southeastern part is drained by the two forks of West Nishnabotna river and the branches and feeders of Soldier river carry the run-off from its northwestern flank. All these streams have their secondaries and tertiaries and so on until a complete

FIG. 36.—Upland of southern Jackson township, looking northeast from the northwest quarter of section 29 across Trinkle creek valley.

dendritic drainage system is developed. On many of the hillsides these minor branchlets are outlined like the delicate tracing of a beautiful pattern. If one stands on any of the numerous ridges which separate these sub-systems a splendid panorama is opened before his view. As an instance let us imagine ourselves on one of the hilltops of southern Jackson or northwestern West Side townships. From our feet the hills roll easily away to broad gently sloping valleys. Looking northwest we see the deep valley of the Boyer, whose floor lies 300 feet below us, with the uplands beyond stretching off into Sac and Ida counties. To the northeast are the headwaters of Tucker, Trinkle and Beaman creeks. See figure 36. If we turn to the south we look over East Boyer to the blue hills beyond. On every hand is the beautiful

17 For an extensive discussion of erosive processes see Gilbert, G. K., Geology of Henry Mts.: U. S. Geog. and Geol. Survey Rocky Mt. Region, pp. 99-150; 1877.

prairie scenery so typical of Iowa. Rich farms with their abundant harvests, gently rolling slopes covered with fields of corn and oats—all these lie spread out to delight the beholder. He would indeed be lacking in appreciation who failed to be touched by such a scene. These hills must be among the highest of the county, rising as they do to heights not far from 1500 feet above sea level or about 250 feet above the East Boyer at Vail.

The difference in the character of the streams entering the Boyer and East Boyer has been mentioned above. To the southeast of the watershed the slopes are not very high nor steep. But on the other side a different type of topography has been developed. The slopes on this side the divide, say along the north line of section 6, West Side, are steeper than those on the south side, all the ravines and valleys are deeper and in consequence the hills stand in bolder relief. Between Trinkle and Beaman creeks the country is strongly dissected and most of it has been cut down below the level of the highest ridges. This condition will be found repeated in many other parts of the county.

The surface of Stockholm and Milford townships repeats in many respects the features found to the east, and the same is true to a large extent of most of East Boyer, of Denison and of Goodrich townships. East Boyer and Boyer rivers have cut deep gashes in the surface and where the tributary valleys open into the major streamways steep slopes have been formed and the neighboring land is more or less strongly rolling. Northern East Boyer and southeastern Milford show rather gentle slopes; the abrupt declivities characteristic of the area tributary to the Boyer are not here developed to such an extent although there is noticed a tendency in this direction as the master stream is approached. The northwest half of Milford, being drained into the Boyer by short watercourses, shows the rugged topography described previously. The ridge which separates the waters running into the Boyer from those flowing into the East Boyer rises 300 feet above Denison. An inspection of the map shows that it divides the township nearly equally. On its south slopes the ravines all have a broad cross section, with gentle grades except near their upper ends, and the creeks flow in wide flat valleys.

The topography of northwest Denison and southwest Goodrich is typical of a mature region. It is well dissected and thoroughly drained. The streams and ravines all have fairly deep valleys and more or less steep walls. In the northwestern part of Goodrich township, however, the hills are less steep, the draws are not so deep and all the contours are toned down and softened. What valleys there are here have very gentle slopes in all di-

FIG. 37.—Upland south of Schleswig, looking north toward the divide from the east line of section 6, Goodrich township. Schleswig may be seen on the horizon.

rections. In fact we are nearing the divide between Boyer and Soldier rivers and the region, as before indicated, doubtless is the largest surviving representative of the old glacial plain. This divide takes the form of an elongate shield stretching from the county line a little to the east of Schleswig and across the western tier of sections in Goodrich township. It reaches an altitude between 1500 and 1550 feet above sea level. A part of this plain is shown in figure 37.

Apart from the region which is directly influenced by the river, Stockholm and eastern Otter Creek townships show fairly gentle upland slopes. From Boyer at 1217 feet the country to the west rises by easy stages 200 feet to where the Chicago & North Western passes under the viaduct between sections 4 and 9, Stockholm. From here a long slope extends to Otter creek a mile west of Kiron whence an equally gradual one rises to Schleswig. As already indicated we shall not expect to find great differences of elevation here but some of the gentle swells around Schleswig rise to 1540 feet, forty feet above the station, 360 feet above Denison. The streams have as yet affected the topography comparatively little. While they have broad valleys these are not far below the general surface of the country. But we must not fail to note that all the land is well dissected, there are no flat areas, all is rolling and reached by drainage lines. From this shield streams radiate in all directions; branches of Otter and Buffalo creeks to east and southeast, forks of Beaver creek and Soldier river to north, northwest, west, southwest and south. From the tops of these swells we can look far south across Boyer river and see the distant hills wrapped in blue haze, or facing northward we may see the broad prairies of Ida county.

The north two-thirds of Washington and the southeast third of Denison are drained by two tributaries of the Boyer, Buck and Friends creeks. They have common characters of high gradients in their upper reaches, and are cutting deep gashes in the hillsides and causing the surface to be strongly rolling. From the tops of the ridges between these streams one may overlook the surrounding country for miles. The deep valley of the Boyer is easily traced and nearer at hand is one swell succeeding another. Descending from the highest hills toward the Boyer valley are a series of long ridges with very gentle slopes toward the river but with steep side slopes to the lateral ravines. These are not sharply set off from the uplands and they extend for almost a mile to the edge of the river valley. There they drop off sharply to the flat bottoms. They seem to be present on both sides of the valley. Possibly they represent a stage in river erosion when the processes of down-cutting were not so active as they have been since, while the inner valley was being cut.

Southern Washington, nearly all of Nishnabotany, the southeast corner of East Boyer, most of Hayes and all of Iowa townships are drained by the two forks of Nishnabotna river and their tributaries. This part of the county illustrates very well the difference in topography produced by streams which empty into a deep, well developed master valley and those which are tributary to a master which has not yet advanced so far in the cycle of erosion. While northern Washington township shows deep valleys with precipitous slopes, south of the watershed the streams present lower gradients and their valleys are marked by slopes which are notably less steep and high than is true of those across the divide to the north. While on that side are steep ravines on this side are gentle swales.

The road from Denison to Manilla follows the ridge between the streams emptying into the East Boyer and those which are directly tributary to Boyer river. In Nishnabotany township the ridge separates the waters of Nishnabotna river from those of Willow creek and the feeders of the Boyer. The divide is nowhere wide, merely a ridge, and overlooks on both sides long slopes usually not very steep except at the heads of draws. These are in some cases quite abrupt. In the vicinity of the East Boyer —Nishnabotany township line the valleys are not so deep as farther north and the surface is less trenched by streams. Still all drainage and erosion lines are mature and the dendritic form of valleys is well developed. In central and southern Nishnabotany the hills are somewhat steeper and higher as the valleys are here nearer to Nishnabotna river and have been cut down toward their base level as determined by the present position of the master stream.

Eastern Nishnabotany and East Boyer townships are a rather strongly rolling upland away from the immediate basin of the river. The northern part of East Boyer is lower and descends gradually to East Boyer river. Numerous short streams trench this slope and render it quite rough in the neighborhood of the valley.

The relief of Iowa township is not so great as is that of some parts of the county, probably not over 200 feet, as shown by the difference in altitude between the east fork of West Nishnabotna river, which just cuts the southeastern corner, and the uplands to the north and northwest. The river flows at about 1300 feet, the uplands stand at 1500 feet or thereabouts. No other township of the county is so little affected by stream work, unless it be Otter Creek. The valleys are all wide and shallow and the same is true of southeastern Hayes even in the vicinity of the river. Most of southwestern Hayes is rather strongly rolling, but as one stands on the road between sections 20 and 29 and looks northeast the country appears nearly level as is shown by figure 38. There are no deep gullies or steep hills, only a few gentle slopes to the east and west. This is on the divide between the two branches which form the west fork of West Nishnabotna river. This divide reaches an altitude of about 1500 feet.

Western Province.—Passing now to the western province of Crawford county we find a different type of topography. It is the resultant of two opposing agencies—erosion and deposition, the latter in part at least contemporaneous with the former. In

FIG. 38.—Level upland in section 20, Hayes township, looking northeast from the southwest corner of the section.

our territory the results probably balance at present although in the country bordering the Missouri the topography is still depositional.

If we journey from Schleswig to the west boundary of the county we shall find that the country is blanketed with an increasingly heavy covering of a very fine yellow silt, which will be described later under the caption "Stratigraphy" as loess. The skyline in this western region is rather more wavy than in the eastern townships, indicating that the loess is piled on the hilltops.

The surface of Soldier and Morgan townships away from the main streams is fairly strongly rolling; erosion lines are well developed though not so strong as in some parts of the county. At the headwaters of the streams the bordering slopes are quite steep but lower down the slopes are more gentle and grade up to the country beyond very easily. These townships are drained by Beaver creek, tributary to West Soldier, and by the headwaters of Middle and East Soldier rivers. The fact that these streams all rise within the area under discussion explains in part the character of the topography. West from the divide at Schleswig, although there is a well-defined slope to the west, the hills become more and more prominent and the valleys deeper, owing largely to the influence of the West Soldier in northwest Soldier township. Nowhere are there any level areas left on the uplands, only narrow ridges which persist in rare instances for a quarter of a mile and then slope off to some valley or ravine.

The four townships to the south—Charter Oak, Hanover, Willow and Paradise—show very well the influence of the streams and the loess on the topography. One characteristic of the border townships is the knobs and cols which form a prominent feature of the skyline and which probably are due partly to deposition of loess, partly to subsequent erosion. In many roadcuts ten to fifteen feet deep nothing but loess is visible, showing what great quantities have been deposited on the hills. As we proceed toward Berne or Charter Oak we note that another feature is the long rolling swells separated by quite deep ravines with slopes which as a rule are fairly gentle, although in some cases they are rather steep, but in every instance are rounded, nowhere angular or sharp. The valleys here are broad and mature and the uplands rise about 300 feet above them, that is, the ridges, for here as elsewhere in the county there is no level land. Indeed the effect of the loess is to accentuate the differences of level since it lies much thicker on the hilltops than in the valleys.

The forks of Soldier river as seen in Charter Oak township have broad flat valleys bounded by low, very gentle slopes. This holds true for Hanover township also. These long slopes rising so gradually may be seen from the ridge road which runs irregularly across Hanover from east to west. (See figure 47, p. 291.) This rises 300 feet above Charter Oak but the ascent is so easy that it does not appear to be such a prominent feature of the landscape. But as we proceed a little farther and get into the basin of the Boyer we see a marked difference, as noted on page 260. Here the slopes are steeper and the gullies have high gradients and very steep heads and appear as deep gashes in the hillsides. Some of the streams have cut their channels ten to fifteen feet deep below the valley bottoms. Paradise creek is of this type. Lower down, as along the north line of section 28, Paradise, the valley is wider but the road which crosses it climbs practically 250 feet in half a mile. Farther west there is another rise of fifty feet or more to the highest points.

The surface of Hanover and Paradise townships is quite deeply loess-covered, but not so much so as is the western tier of townships. Nor is the tendency to the hummocky topography so marked. This difference is plainly marked as we stand on the high ridges between Paradise and Willow townships and look east or west. The sky-line in the two directions is very characteristic of the two types of topography developed here.

The topography of Willow township is decidedly rough, with rounded knolls piled high with loess and rather steep slopes to the minor drainage courses. The roads are continually up and down, over one ridge after another. There is more of the knobby effect than is true farther east and many of these knobs seem to bear no immediate relation to the drainage lines. These tend to give a rolling, wavelike effect to the surface. The major streams, the branches of Willow creek, have fairly gentle valley walls except near their heads. But some streams in the southeastern sections are tributary to the Boyer and these affect the topography in typical fashion. Their master stream is close by and in a deep valley, while Willow creek has a long gentle course before it reaches its master—the Missouri.

While Boyer and western Union townships belong in the western province they are so far under the influence of Boyer river that their topography for the most part resembles that of the eastern province. This is especially true of Union township. The eastern part of this township resembles Washington in showing the effect of the short streams running north to the Boyer and the longer ones which flow southwest into Shelby and Harrison counties before they finally empty into the Boyer also. This township, therefore, presents very little if any of the typical loess-built topography so characteristic of Willow township.

Northwestern Boyer township is far enough from the river to allow of the development of the loess topography and in this it resembles adjacent parts of Willow township.

Benches.—As a minor topographic feature but one still worthy of note may be mentioned a series of benches occurring along some of the streams. These were observed only along the Boyer below Denison and in the valley of West Soldier river. At a few places in the lower part of Beaver valley there seem to be indications of small benches, as in section 8, Morgan. At the junction of the creek with West Soldier another bench occupies the fork and at two places along the Soldier are well-defined benches, namely one in sections 2 and 11 and one in 20, with a smaller one in section 30, all in Soldier township. All of these stand about ten feet above the flood plain, while this in turn is five feet or less above the stream. They may have a foundation of drift and no doubt have, but they are completely covered, so far as could be seen, with a veneer of loess. At the free edges where the steep slopes are in some cases bare of vegetation only loess can be seen, even to the bases. They are in general well marked from the flood plain both by superior height and by the presence along most of their free edges of a steep slope. In some places a narrow flood plain separates them from the stream, elsewhere the water washes their bases. The junction between the benches and the upland is generally marked by a well defined curve.

Along the Boyer the benches are larger and stand at greater heights above the valley floor. The principal ones are a large one just south of Friends creek, one in section 11, Union, small ones on either side of the mouth of Paradise creek valley and a long narrow one stretching across sections 23, 22, 26 and 27, Boyer. This is less than half a mile wide and is two miles or more long. On a hillslope, about fifty feet above the valley, back of the schoolhouse at the west line of section 13, just where the bench begins as a narrow strip between hills and plain, a small pit has been opened in coarse sand and gravel to a depth of eight feet. The gravel is rust red and gray, with its granites rotten and crumbling. It extends to the grass roots. One hundred feet higher the hill is capped with loess, of which twenty feet are exposed by slumps along the steep slopes. A mile to the southwest in the center of section 23, where the road ascends the face of the bench from the flood plain, it has been cut through twelve feet of loess which completely covers the underlying materials. A line of seeps and springs along the base of the bench from this point southwest for over a mile seems to mark the outcropping edge of a sand bed which lies between drift and loess. Near the middle of the west line of section 26 several gravel pits have been opened at the low edge of the bench and show ten feet of sand with streaks of gravel and abundant coarse material. Some bowlders which have been thrown aside are four by five by two feet in dimensions. The sand here is clean, gray and cross-bedded and is overlain by three to six feet of yellow loess. Nowhere was drift observed along this bench, although it may form its foundations, beneath the later materials. The same is true of the bench on the east angle of the mouth of Paradise valley, in

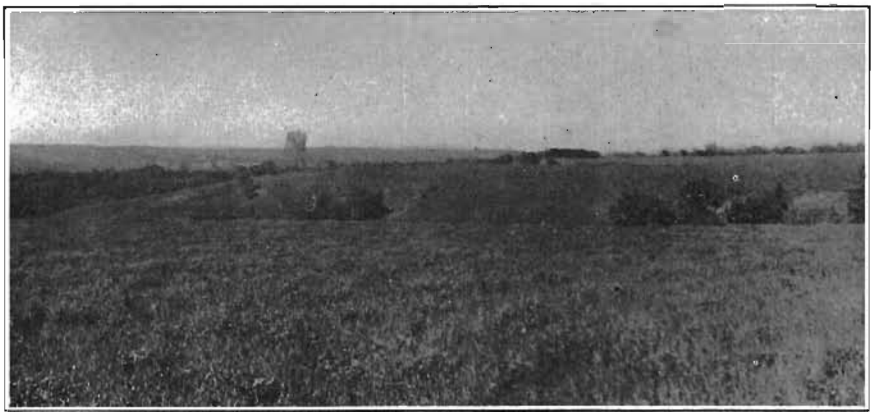

FIG. 39.—A bench on the south side of Boyer valley between Arion and Dow City. Shows abrupt slope to the river and the flat top. Arion in the distance.

which the Riddell gravel pit is located, and of the bench northeast of Dow City in which two pits expose twenty feet or more of sand and gravel with some silty bands near the top. Four to eight feet of loess overlies the sands of the Riddell pit. Sands and gravels are exposed also in the mouth of Friends creek and on the bench just south of it.

These benches rise forty or fifty feet above the valley and have rather steep slopes on the free edge. Their surfaces are fairly level and are in some cases trenched by ravines which cut back into the country for several miles.[18] Figure 39 shows one of these benches below Arion.

ALTITUDES

The greatest range in altitude in Crawford county is about 450 feet from the high points of Morgan township to where the

18 The subject of river benches is thoroughly discussed by Professor Shimek in his report on Harrison and Monona counties, this series, vol. XX, pp. 287-292.

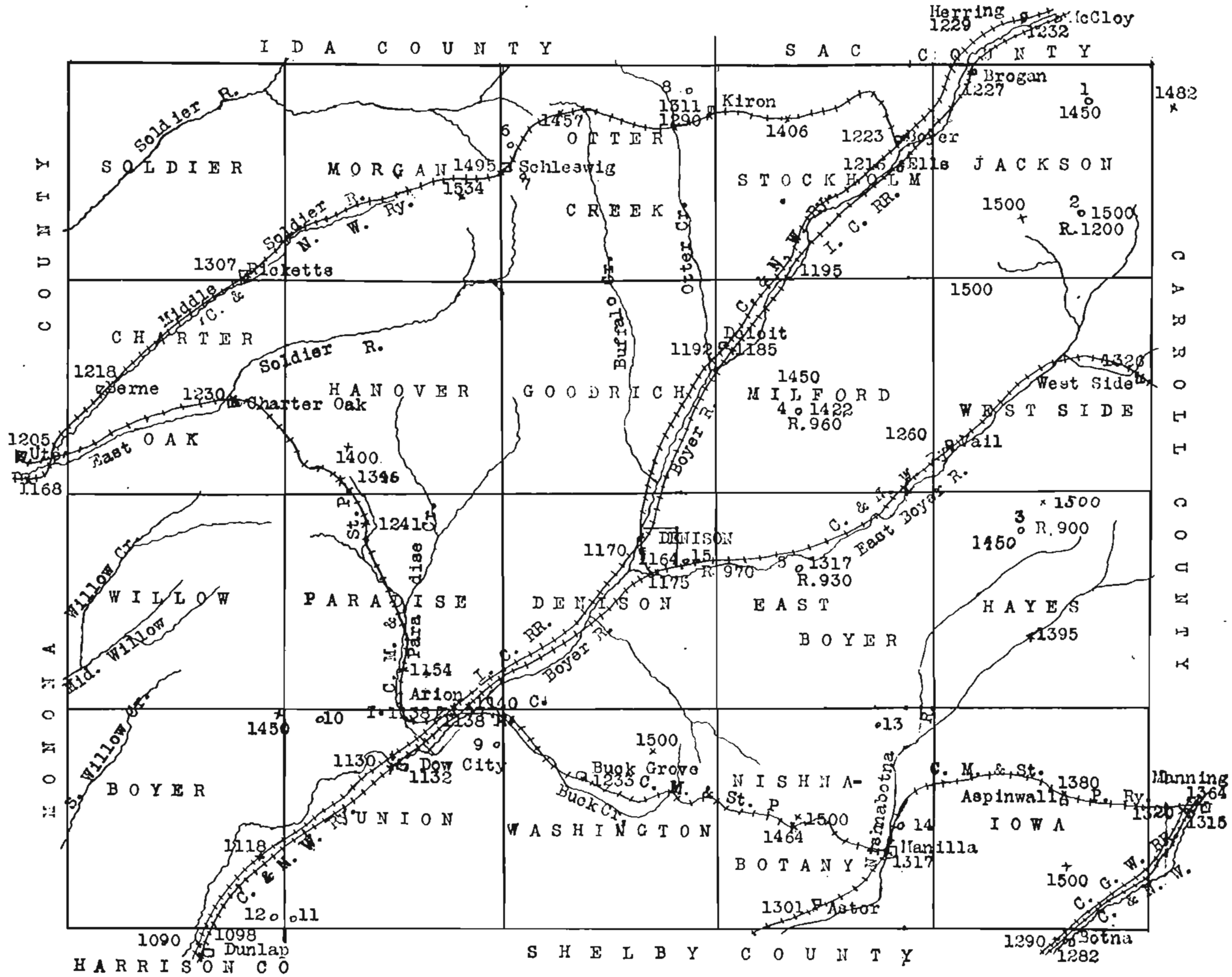

FIG. 40.—Outline map of Crawford county showing elevations (large numbers) and principal wells (small numbers). Well numbers are: 1, Lorenson; 2, McCaffery; 3, King; 4, Miller; 5, Franklin; 6, Herring; 7, Naeve; 8, Shurkey; 9, Talcott; 10, Woodruff; 11, Kern; 12, Davie; 13, Baker; 14, Woodard; 15, Denison.

Boyer crosses the south county line at Dunlap. For any limited area the relief is, of course, less than this. In the territory drained by the Nishnabotna system it is scarcely over 200 feet, in that tributary to the Soldier forks it is about 300 feet and in the basins of the Boyer and East Boyer it amounts to 300 to 375 feet. These figures represent the depths to which the stream valleys have been incised below the level of the divides except that an unrecorded lowering of unknown amount doubtless has taken place over the entire county. If we consider how slowly this process of stream erosion is going on we may gain some idea of the vast length of time during which the rivers and brooks of Crawford county have been at work.

In common with all of western Iowa our area shows a slope to the southwest, but this slope is very gradual and in some cases seems to be almost nonexistent. Still it is true that the northern townships rise to greater heights than do the southern and the southwestern township is certainly lower than the northeastern. On this point consult the accompanying diagram, figure 40.

The altitudes of the railway stations along the Boyer valley are given below. Those in *italics* are Illinois Central stations, those in roman are Chicago & North Western stations.[19] *McCloy, 1231 feet;* Herring, 1227; *Brogan, 1232*; Boyer, 1217; *Ells, 1221*; *Newcom, 1200*; Deloit, *1190,* 1185; crossing of North Western and Illinois Central tracks at Denison, *1169,* 1170; Denison, *1169,* 1171; Arion, *1143,* 1138; Dow City, *1136,* 1131; *Haley, 1122*; Dunlap, *1095,* 1094. From Arcadia to Denison the altitudes are: Uplands just north of Arcadia, 1430 feet; Arcadia station, 1386; West Side, 1324; Vail, 1257; Denison 1171. A section along the Mondamin branch of the Chicago & North Western railway gives: Boyer, 1217; ridge, section 9, Stockholm township, 1420; Kiron, 1307; Otter creek, 1290; ridge, section 10, Otter Creek township, 1455; Schleswig, 1493; hill crests one mile west of Schleswig, 1534; Ricketts, 1303; Berne, 1213; Ute, 1166. A similar section along the main line of the Chicago, Milwaukee & Saint Paul railway gives: Manning, just east of the county line, 1364 feet; Aspinwall, 1380; divide two miles west of Aspinwall, 1428, Manilla, 1317; Astor, 1301. Elevations along the Sioux

19 The altitudes along the railroads of Crawford county are taken from profiles of these roads very courteously furnished by the chief engineers.

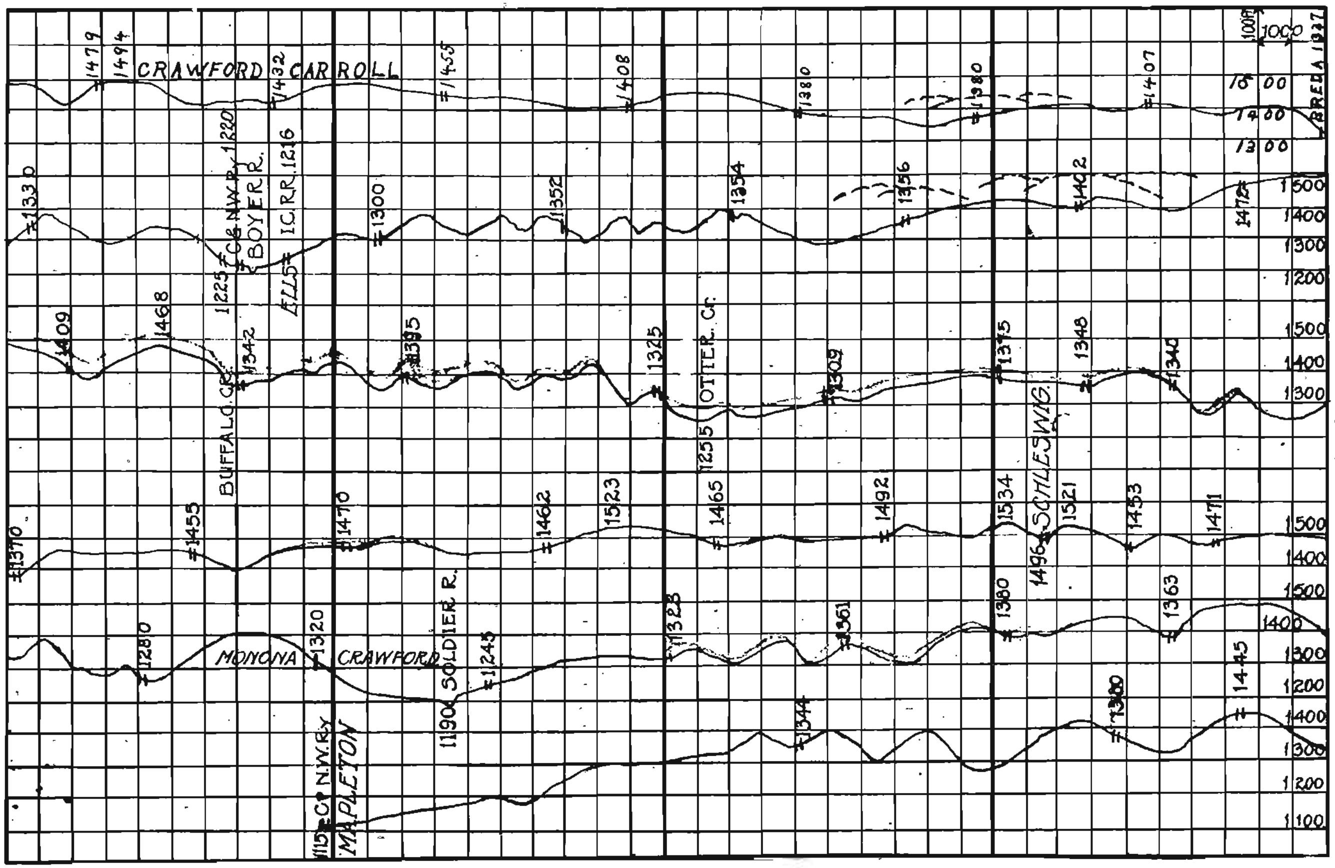

FIG. 41.—East-west profile from Breda in Carroll county across Crawford county to Mapleton in Monona county. Short double lines indicate north-south roads. Elevations in feet above sea level.

City line are: divide three miles west of Manilla, 1464 feet; Buck Grove, 1233; Arion, 1138; Bell, 1155; Kenwood, 1241; saddle between Paradise and Emigrant creeks, section 32, Hanover township, 1346; Charter Oak, 1230; Ute, just west of the county line, 1202. The Chicago & North Western station at Manning is 1324 feet above sea level and that at Botna, just south of the southeast corner of the county, is 1292 feet above sea. The Chicago Great Western stations at these two towns are at 1320 and 1290 feet respectively. The stations of both roads are in the valley of the Nishnabotna, while the Milwaukee station at Manning is above the valley floor. The profile from Breda to Mapleton, figure 41, will give an idea of the nature of the topography in the northern part of the county.

Drainage

It has been mentioned above that the drainage of Crawford county is to the Missouri. Several sub-systems of streams take part in this drainage and all but one of them, Nishnabotna river, reach the great stream within the limits of Iowa. Most of the streams of the county are gathered together beyond its borders to form larger tributaries of the Missouri although the main drainage course of the county, the Boyer, empties its waters directly into the master stream a few miles above Council Bluffs.

The discussion of the topography of the county will have shown that the drainage of Crawford is very thorough. Probably there is scarcely a square mile anywhere within the county, unless the Boyer valley near Dunlap be excepted, which is not thoroughly drained. And the drainage systems themselves give every evidence of maturity, for even the smaller streams flow in broad valleys and meander across more or less perfectly developed flood plains. It is very plain to be seen that the present drainage courses of the county have been at work a long time and have had plenty of opportunity to become thoroughly established.

The drainage of the county is without exception *consequent*. That is, the position and direction of the valleys are dependent upon the topography of the surface after the retreat of the Kansan ice. So far as can be determined none of the valleys are preglacial nor are they affected at all by the underlying bed

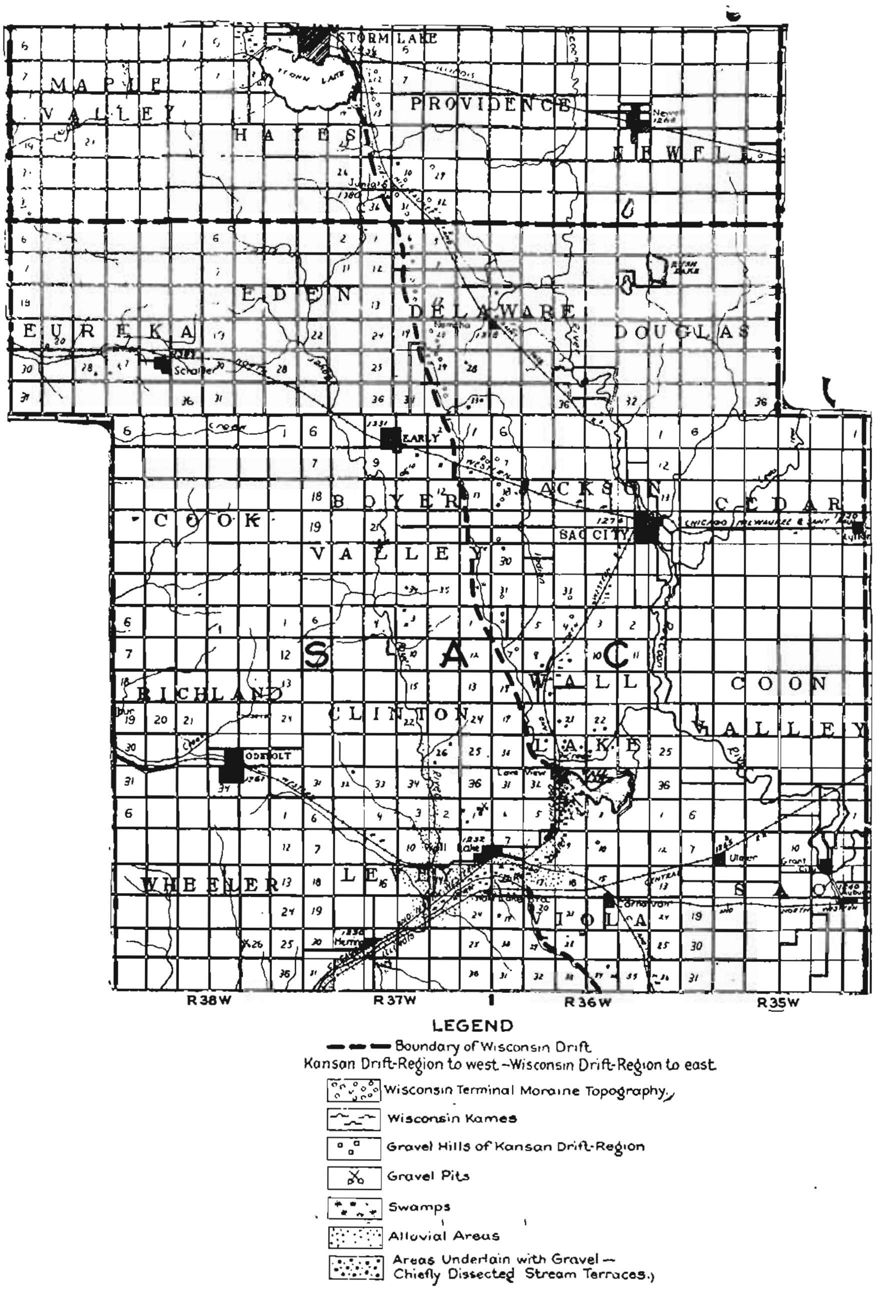

FIG. 42.—Outline map of Sac county showing upper courses of Boyer and Raccoon rivers. From Carman.

rock. Indeed none of them has cut through the mantle of glacial debris to the rock below. The valleys now occupied by the Boyer and perhaps some of the other streams in the county may have been in existence before the Kansan glacier covered the region but if so they were filled to a greater or less degree during the Kansan invasion and have had to be reexcavated since that time. Hence the present streams are post-Kansan, whatever the age of their valleys.

FIG. 43.—View southwest down the wide sag and the narrower valley of Boyer river at their junction in section 22 of Levey township, Sac county. The river is marked by the line of trees across the view in the middle distance. The bluff on the right marks the narrowing of the valley.

Boyer River.—By far the largest stream of the county and the most important in its influence on topography is Boyer river. This stream rises in the Kansan uplands south of Storm lake and flows a little east of south across Sac county past the town of Wall Lake where it turns to the southwest. In this direction it crosses Crawford county, which it divides into practically equal parts. In its course across Crawford county Boyer valley

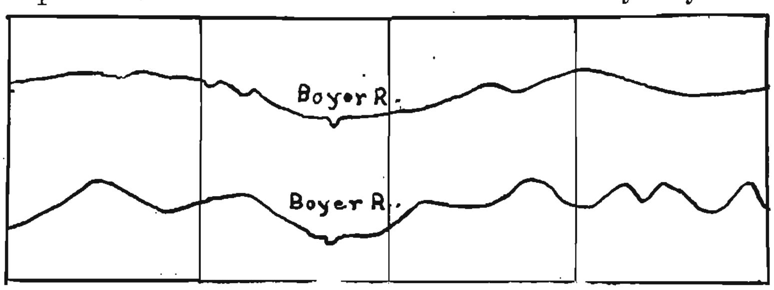

FIG. 44.—Profiles across Boyer valley. The upper one, west of Lake View, Sac county, shows the wide shallow sag valley. The lower one, at Ells, Crawford county, shows the deep narrower steep-sided valley below the sag. Scale: horizontal, 1 inch equals 4000 feet; vertical, 1 inch equals 400 feet.

is of the normal mature type but in southern Sac there opens into the valley from the northeast a broad sag which extends southwestward from Wall Lake. Digitate alluvial plains also extend several miles up the valley of the Boyer above the mouth of this sag and up the valleys of two tributaries from the eastern flank of the high ridge east of Odebolt. The flat undrained sag although two or three times as wide as the Boyer valley at Herring or Boyer is nevertheless a direct continuation of it. On the other hand the present course of Boyer river north of the sag is out of line and out of harmony with the valley below. These features are shown in the map of Sac county which forms figure 42 and in the view shown in figure 43.

While, as will be explained below, Boyer valley in Crawford county and in southwestern Levey township of Sac county is flat floored and steep sided, above the junction with the sag the valley has a sloping floor and widely flaring walls. The two profiles across the valley given herewith as figure 44 will make this more clear than words can do.

In strong contrast also to the valley in Crawford county is the character of the sag in the vicinity of the town of Wall Lake. Its floor is almost perfectly flat and its sides slope rather gently away to the upland, especially east of Wall Lake. West of here they are somewhat steeper and higher, in the vicinity of the valley of Boyer river and of the high ridge west of the upper Boyer.

What seems to be the most reasonable explanation of this unoccupied sag is that it is a fragment of a branch of an ancient Boyer valley which once included the basin of Wall lake, or at least a part of it, and possibly Indian creek. An arm of the sag extends to the southeast as far as Carnarvon and may represent the lower part of another branch of this old-time system. A little stream now comes down along this branch from the higher land near Breda in northwestern Carroll county and empties, or did empty, into the southern arm of Wall lake.

It is very natural to assume that the lower part of Indian creek valley, east of Lake View, and Raccoon river above the mouth of Indian creek may have formed the main upper Boyer river. However, there are several facts which seem to stand in the way of such an assumption. Opposite Lake View the valley of Indian creek is half a mile wide and fairly flat floored. It is capacious enough to accommodate a much larger stream than the one which now occupies it. But within a mile to the west the valley is shallower and the walls are gentler. This is perfectly normal, but it seems anomalous to find on descending the valley from Lake View that about a mile and a half below the town the valley walls approach each other abruptly and from here to the mouth are nowhere more than one-fourth mile apart and in many places are so close as to leave almost no room for a flood plain. The outlet creek of Wall lake is likewise a small stream in a narrow rather shallow valley.

Indian creek northwest of Lake View lies just within the edge of a belt of rough country known as the Wisconsin moraine which forms the margin of a sheet of glacial drift which is called the Wisconsin. This moraine is much less prominent about the lower course of Indian creek, and the country here is much smoother and more level prairie.

Wall lake is separated from the valley of Indian creek at their closest approach merely by a strip of hills and hollows not over one-fourth mile wide. The lake level is about twenty feet higher than that of Indian creek, although this probably is due to inequalities in the thickness of the moraine. The sag just south of Wall lake is filled with gravel to a height of thirty feet above the original floor and similar gravel no doubt underlies the lake. The assemblage of facts seems to indicate that while the ancient valley may have included the sag, the western part of Wall lake and the wide part of Indian creek near Lake View it could hardly have included the lower valley of the creek to the east.

If Raccoon river above the mouth of Indian creek once formed part of the Boyer system we should expect to find some differences in the character of the valley above and below this point. The valley above the creek mouth should show some evidence of being older than the lower part. But the evidence does not point in this direction.

Opposite the mouth of Indian creek valley Raccoon valley is remarkably wide, stretching nearly a mile from rim to rim. However, the actual flood plain is quite narrow and is nowhere more than two hundred or three hundred yards wide. The remainder of the valley is occupied by a high second bottom or terrace which is really a valley filling of gravel and clay from the

Wisconsin glacier. The old walls rise rather gently above this terrace and mark the former limits of the valley. A very significant feature of the valley filling is the fact that it extends from two miles above the mouth of Indian creek at least two or three miles below that point. That is, there is no change in the character of Raccoon valley near the mouth of Indian creek. In fact all along its course below here the valley shows evidences of its pre-Wisconsin age in its dimensions and its form.

Above the point already mentioned where the valley widens out and is partly filled by Wisconsin drift materials the valley is narrow and deep, steep bluffs flank the narrow flood plain and in its present aspects the gorge presents the appearance of post-Wisconsin age. Similar features are the rule in the valley from here to and beyond Sac City and as far at least as the north county line. In a few places, however, the valley shows what seem to be remnants of an original pre-Wisconsin drainage course. One of the best of these is in sections 25 of Delaware and 30 and 31 of Douglas townships, where the valley flares out into a wide open bay about a long oxbow. Another is just above Sac City, where the valley shows evidences of filling; and other indications of the incomplete filling of an old valley are not wanting.

The conditions seem to point, then, to a pre-Wisconsin age for Raccoon valley throughout its extent across Sac county. There can be no doubt of this age in its lower portions. If, therefore, Raccoon valley is pre-Wisconsin in origin and its stream flowed to the Des Moines then as now, where was the pre-Wisconsin course of the upper Boyer? In view of the width of the valley of Indian creek opposite Wall lake, although it is just within the terminal moraine where deposition would naturally be great, and in view also of the narrowness of the valley farther east and of the character of Raccoon valley, it seems as if we must look for the northward continuation of the ancient Boyer valley in this wide segment of Indian creek valley and possibly in the narrower portion to the northwest. Possibly, of course, the old valley above this larger segment may have been entirely filled up and obliterated.

It seems evident from the character of the modern upper Boyer valley that it has had a different history than the valley in Crawford county, and it probably was only a branch which united with the other which came from the northeast. Macbride indeed sketched such a history as this in one of his reports,[20] but later in discussing Sac and Ida counties[21] he postulated an *eastward* flowing Boyer river whose headwaters were gathered from the ridge which stretches between Schaller, Odebolt and Herring (see figure 42) and now is cut through at the latter village. This theory seems to be based on the narrowness of the valley at Herring and Boyer, but it seems as though this narrowness may well be explained by the presence of the high ridge which would naturally require more work to excavate and hence might well be cleft by a valley narrower than that above or below. It may freely be admitted that the unoccupied valley in the vicinity of Wall Lake is abnormally wide but this may be accounted for in part by the fact that several streams converged south of Wall lake and in part by the greater ease with which the river could widen its valley here than in the much deeper and more steep sided part between Herring and Deloit. On the other hand it is hard to believe that a stream would normally make such a sharp turn as would be necessary for the present upper Boyer if it had to flow eastward past Wall Lake to the Raccoon.

Again it is only since the time of the last glacial invasion, the Wisconsin, that these drainage changes could have occurred and in view of the immaturity of much of the upper part of the Raccoon valley as sketched above we should according to Macbride's theory expect similar immaturity in the Boyer at Herring. However, the valley here is uniform with that below in its maturity, and it would be unlikely that either the very short stream postulated as rising on the eastern slope of the divide near Herring and flowing eastward past Wall Lake, or even the much longer one rising on the western side and flowing southwest, should, during the brief time allotted, have cut out such a wide valley and developed such a mature flood plain as now exist, both in the unoccupied sag valley near Wall Lake and in Boyer valley near Herring and in increasing measure to the southwest.

20 Geology of Cherokee and Buena Vista counties, Iowa Geol. Survey, vol. XII, pp. 330, 331, 337.

21 Geology of Sac and Ida counties, Iowa Geol. Survey, vol. XVI, pp. 520, 523, 524; 537.

Professor Todd[22] has recently argued that Niobrara river of northern Nebraska during pre-Pleistocene time "followed the courses of James and Missouri rivers as far as Onawa, Iowa, thence east and northeast through Ida and Sac counties past Wall Lake and thence southeast along the Raccoon river. This conclusion rests on a few apparently reliable reports from wells which show that the preglacial surface indicates a valley whose bottom is less than 900 A.T., in some cases less than 850." "The fact that Wall Lake lying on the summit formerly drained into Boyer river and now into the Raccoon, and another fact that the Boyer rises east of the crest of the divide, has first a course east of south and at this point turns southwest" are considered to be explained by this theory. Such well records as are available to the writer do not indicate such a valley as Professor Todd postulates and while Wall lake and the sag valley doubtless partly suggested the theory it must be remembered that the lake is of late Wisconsin age and the valley doubtless is to be dated not earlier than the close of the Kansan. These facts seem to invalidate the whole argument since Professor Todd is discussing a preglacial stream.

Professor Todd further states that: "There was a fall of 350 feet from Sioux City to Wall Lake." But at present the elevation of low water in Missouri river at Sioux City is 1076 feet, while the elevation of Wall lake is about 1225 feet. There is no indication of such a warping as would be necessary to equalize the discrepancy between these figures and the grade indicated by Todd. In fact the evidence seems to point to uplift in northwestern Iowa during glacial times rather than to the depression which seems to be necessitated by Professor Todd's hypothesis.

Doctor Carman has recently restated the theory of an eastward flowing Boyer in his report on the Pleistocene Geology of Northwestern Iowa.[23] Carman emphasizes the facts that the Mississippi-Missouri divide is lower than the minor divide a few miles to the west and that the pattern of drainage on opposite sides of the Mississippi-Missouri divide is the same while

22 Todd, J. E., The Pleistocene History of the Missouri River: Science, N. S., vol. XXXIX, Feb. 20, 1914, pp. 263-274.

23 Iowa Geol. Survey, vol. XXVI, pp. 318-320; 1915.

that on opposite sides of the minor divide is different. He states his theory in the following language:

> In pre-Wisconsin time the Boyer river turned eastward and passed through the Wall Lake outlet toward Raccoon river. When the ice-edge blocked this eastward drainage the ponded waters in the valley broke over a low place in the great watershed near Herring, in southwestern Levey township (Sac county), and escaped to Missouri river. This course was cut so low during ice-occupancy, and the old valley to the east was so much filled that the Boyer continued to flow to the southwest and did not again take its eastward course to the Raccoon.

Some of the objections to this theory have been set forth in previous paragraphs. The fact that the pattern of drainage on opposite sides of the minor divide is different may be explained by the statement that the Boyer is close to the crest of this divide and there is little room for west-to-east tributaries to develop, while the Maple flows, in a nearly parallel course, be it noted, several miles distant from the crest, and therefore a well developed system of east-to-west tributaries drains this western slope.

The question rises as to why this overflow from the ice-ponded waters should seek escape over the highest part of the bounding rim rather than over some lower col. A study of the altitudes of the region shows that in northwest Carroll county, along the margin of the Wisconsin moraine, the highest point reached by the railway between Carroll and Wall Lake is 1366 feet, at Breda. This is practically at the upland level. The railway between Wall Lake and Odebolt crosses the high divide west of the Boyer at 1378 feet. But in northeast Crawford county, where the Boyer has cut its valley through the ridge, the latter rises 1500 feet or more above sea level east of the river and over 1450 feet between the Boyer and Otter creek, while a little farther west, near Schleswig, the hills reach altitudes well over 1500 feet above sea level. There is no obvious reason why this high plateau, apparently the highest land south of Alta, should be chosen as the locus of overflow for the glacial flood-waters. On the other hand, however, if the southwestward flowing post-Kansan Boyer be conceived of as extending its valley to the northeast by headward erosion there is apparently no reason why one of the vigorous members of its dendritic system should not work its way up the slopes of the highlands and eventually cut through what was once the real Mississippi-Missouri divide and so come to gather in a part of the run-off which really belonged to the Raccoon system, although perhaps the Boyer never actually tapped any of the chief feeders of that system. This would seem to account satisfactorily for the deep narrow valley through the ridge and the broader shallower one to the east of it. Then when the Wisconsin glacier overwhelmed the east branch of the upper Boyer system and the moraine obliterated most of its valley the empty sag remained as a testimonial to former conditions and the west branch became the main stream of the system.

Note may be made here of the presence in Porter creek valley north of Boyer, as well as in Otter and Buffalo creek valleys and also in Boyer valley at several points, of gravels which are older than the Wisconsin stage and which therefore show that the present drainage features were established before the Wisconsin ice disturbed the pre-existing drainage. These gravels will be described later in connection with the glacial materials. (See pages 328 to 338.)

Mention may be made also of the fact that at several points along the walls of Boyer valley, below the junction with the sag, as for instance in the southwest quarter of section 14 and the middle of section 31, Levey township, Sac county, loess is present only about fifty feet above the valley floor, or fully half way down the slopes. This would seem to be inconsistent with a Wisconsin age of this part of the valley, as the loess is older than the Wisconsin drift, and should have been eroded away while the valley was being cut if it were present at that time.

It seems to the writer, then, to summarize, that Boyer valley originated at some time following the retreat of the Kansan glacier from western Iowa and that the river developed the course now occupied across Harrison and Crawford counties, while in Sac county there were two branches, the western of which is now the upper Boyer, while the eastern is represented by the empty sag extending from the river to Wall lake, and beyond here perhaps by upper Indian creek. The Wisconsin glacier blotted out the upper part of this eastern branch, leaving the lower part as a partly filled undrained marsh beyond the glacier's margin. It seems that the sag valley and the river valley as well are too mature to have been the result of Wisconsin and post-Wisconsin erosion alone. Their history goes far back of Wisconsin glaciation through the uncounted years and centuries of the development of the deep-cut topography on the Kansan plain.

Where Boyer river enters Crawford county it occupies a comparatively shallow valley. The immediate valley walls are not over one hundred feet high although the more distant hills of the uplands rise another hundred feet or more. The flood plain is approximately one-fourth mile wide and shows numerous abandoned channels and oxbows which give evidence of the meandering of the stream. One of these oxbows, in section 7, Jackson township, is especially well marked. Many of these channel-remnants are filled with water, making miniature lakes. However, the entire valley with these exceptions is well drained and raises excellent crops of corn and other cereals. This condition holds true in Sac county as far east as section 23, Levey, or in other words as far as the valley is occupied by the river. East of here, however, where there is no natural drainage the valley was formerly marshy and was useful only for pasture or meadow land. In recent years, however, two large drainage ditches have helped to make these fertile fields more available for agriculture.

From the county line, then, southward past Boyer the valley retains similar characters, although it is appreciably deeper toward the south. With the increase in depth comes also a greater steepness of slope which is especially noticeable on the east wall of the valley. In connection with this feature may be mentioned that of a greater covering of timber on the east—the northwestward—facing wall. This holds true down the river and even to a greater degree as the walls grow steeper with increasing height. This difference in steepness and growth of vegetation on the two sides of a valley has been noted often in the studies of Iowa geology and is explained below in connection with East Boyer river.

Nearer Deloit the valley is deeper and the same is true toward Denison, but it does not grow much wider. Near the latter town it is about a third of a mile wide and is filled with alluvium to a considerable depth. The river channel is cut in this mass of filling to a depth of ten feet and meanders across the plain from side to side. Beneath this modern filling is a layer of gravel which forms the aquifer for numerous wells, such as those which formerly supplied the city of Denison.

At Denison the East Boyer joins the main stream and from here to the county limits the valley is much wider, from two-thirds to one mile. Between Denison and Arion the relations of the valley walls are reversed and the west wall is steeper than the eastern. There is very little timber on either side, only a little brush at intervals. The east wall is in many places so gentle that it is tilled from the uplands to the river and there is no break in the slope.

Between Arion and Dunlap, which latter town is just beyond the county border, the Boyer valley is quite wide, a mile or more, and the immediate valley walls are gently sloping and not very high. However, the surrounding country rises fully three hundred feet above the stream. In the last mile or two of its course in the county the valley is somewhat swampy and a few ponds are present. Elsewhere it is well drained and very fertile.

East Boyer River.—The principal tributary of the Boyer is East Boyer river. It is formed by the meeting in central West Side township of two groups of small streams which rise on the uplands of western Arcadia township, Carroll county, and southern Jackson township, Crawford county. Their united waters flow southwest to meet the Boyer at Denison. While not a large stream it has a wide valley and is of considerable topographic importance. The valley in West Side township and for a few miles west of Vail is not so deep as is that of the Boyer above Denison. It may be said to be a mile wide between the tops of the walls in the vicinity of Vail, although the upland levels are not reached for more than this distance from the flood plain. The slopes are very gentle for the most part and merge gradually into the flood plain. These gentle slopes persist within three miles of the river's mouth, but are replaced by steeper and higher walls near the Boyer valley. These are shown in figure 45.

All the secondary streams which empty into the East Boyer have made wide valleys and the larger ones have developed alluvial plains in their lower courses. But all are quite swift and have a fairly steep fall. This is true also of the main stream as the elevations of West Side (1324 feet), Vail (1257 feet) and Denison (1171 feet), show. A notable feature of these tributaries is that many of them maintain their gentle slopes right up to their heads and do not show the steep head concavities developed by some of the steeper ravines and other streams in some parts of the county and elsewhere in the state, notably in the loess

FIG. 45.—View east of south across East Boyer valley from the southeast part of Denison.

bluff region. Almost every valley and ravine has its little stream, fed for the most part by seepage springs, which are very abundant.

It will be seen from an inspection of the map that East Boyer river along nearly its entire length flows much closer to the south edge of its flood plain than to the northern margin. At the same time the south facing slopes are gentler than are those which look toward the north. The laws governing these conditions have been so well stated by Calvin[24] in his report on Johnson county and the situation there described applies so admirably to the present case that no better means of presenting these laws here can be taken than to insert his statement bodily. Doctor Calvin's discussion follows:

The original gently sloping surface of the great drift sheet after the retreat of the Kansan ice, in the region under discussion (Johnson county), was drained by a number of parallel

24 Calvin, Samuel, Iowa Geol. Survey, vol. VII, p. 51; 1896.

streams, each flowing toward the east. As soon as these streams cut channels of any considerable depth, the two sides of each channel were differently affected by the agents of erosion. The northward facing surfaces suffered less than the opposite side of the channel from the alternations of freezing and thawing and consequent effects of erosion, in early winter and spring. They were less affected by the droughts of summer, which tended to check the growth of vegetation and render the surface more pulverulent and more easily attacked by dashing rain storms. The result was that as the channel was deepened the north side of the valley receded more rapidly than the south, the slopes soon became gradual, the small lateral streams on the north cut back into the highland with greater facility and greater speed, robbing the secondary streams developed on the south side of the next drainage area to the north; and so as a result of normal causes each drainage basin became unsymmetrical and was converted into a sloping plane with the main drainage stream along its southern margin. The east-west streams of the driftless area show similar effects as a result of the same cause, only the effects are modified in consequence of the fact that the stream valleys are cut in indurated rocks in place of the loose materials of the Kansan drift. The northward facing bluffs, however, are steeper than those on the opposite side of the valley. They are generally wooded, or at least are clothed with ranker vegetation that affords protection from atmospheric disintegration. As a result of the larger amount of material carried down from the southward facing slopes on the northern side, the bottom of the valley inclines southward, and the stream runs close to the foot of the steep bluffs that face toward the north.

Minor Tributaries.—The other tributaries of Boyer river are for the most part small streams of no great consequence. The most striking characteristic about these small branches is the fact that they occupy valleys whose size seems entirely out of proportion to the small amount of water now flowing through them. Of course this is due not so much, and not chiefly to the presence of greater amounts of water in times past, but to the fact that the streams meander across their valleys and also to wastage of the valley walls as described by Doctor Calvin.

From the east there enter the Boyer between the north county line and Denison, Beaman creek which drains northern Jackson township, Trinkle creek, a smaller stream carrying the runoff from the central part of the same township, and Tucker creek in southern Jackson and Stockholm townships. All of these have typical wide valleys, broad flat bottoms, with rather gently sloping walls, especially on the north side, and in each case the stream is cutting into its south bank. As an instance of the size of these valleys it may be stated that that of Trinkle creek is over two miles wide from ridge to ridge in section 17, Jackson. This creek is also fairly typical in its rate of fall. It drops thirty feet in the last mile of its course, forty feet in the next to the last and fifty feet in the third mile. Beaman creek has about the same fall.

Between Tucker creek and East Boyer river there are only small brooks entering the Boyer from the east. South of Deni-

FIG. 46.—Steep headwater slopes of the tributaries of Buck creek. View in sections 9 and 10, Washington township.

son Friends creek and Buck creek are the only tributaries of consequence on the east side. Friends creek still flows through a deep, narrow, steep-sided valley in most of its course, although this is wider in the last mile or so. The gorge is filled down to its mouth with forest trees of various species. Friends creek drains southeast Denison together with a few sections in East Boyer, Nishnabotany and Washington townships. Some of its headwaters are gathered close to the sources of Buck creek, which gathers in a large part of the runoff of Washington township. A narrow flood plain extends up Buck creek as far as Buck Grove, beyond which village the valley has the usual characters of Kansan streams: great depth with considerable width, high gradient in its upper reaches and strongly concave slopes at the heads of its secondary and tertiary branches, as is typified by figure 46. These branches head about 1450 feet above sea, three hundred feet above the Boyer at Arion, and in the first three miles of its course the stream falls about one hundred and fifty feet, a good instance of the high gradients of the short streams emptying into the Boyer. The master stream with its superior cutting power and consequent deep valley has forced its tributaries, in order to keep their valley mouths at the level of the larger valley, to adopt steep grades with consequent high velocities. This process has, however, ceased for many of the tributaries in their lower reaches, and they are now engaged in building up alluvial plains.

The upper branches of Friends creek give a good illustration of the dendritic type of drainage which is so well developed in this county. Three or four branchlets stretch up into the country with fairly gentle grade, with broad, gently rounded valleys and with numerous little gullies and feeders which reach up the walls and end in rather deep concavities in the hillsides. As one looks over the brink of the valley this miniature drainage system appears incised into the depths beneath as if engraved by a giant sculptor.

The streams which enter the Boyer on this side below Buck creek are of insignificant proportions and this is true also for those which drain those parts of Boyer and Union townships to the west of the river.

The chief tributaries of the Boyer from the west are Paradise creek, which drains the township of the same name, as well as southeast Hanover; Buffalo creek, which drains central Goodrich and Otter Creek townships; Otter creek, which flows near the east line of these two townships; and Porter creek, which joins the main valley at Boyer. These streams have the usual characters of the Boyer tributaries. The headwater ravines of Paradise creek have very steep slopes and are cutting into the hills. Lower down where the gradient is less a flood plain has been built up. Here the side slopes are less steep but still the valley is increasingly deep, two hundred and fifty to three hundred feet from ridge to flood plain.

Buffalo creek is worthy of mention because of its extremely long though narrow alluvial plain. This extends across Goodrich and two or three miles up into Otter Creek township. The valley is very mature and is bounded for the most part by rather gentle slopes. In section 15, Goodrich, the hills stand close to the stream and reduce the width of the valley to almost nothing. Below this point the valley again is wider to the Boyer.

Otter creek is a typical Kansan stream, with broad, mature alluvial floored valley for several miles above its debouchure at Deloit, and with side walls gently sloping for the most part, here receding far from the stream, there drawing closer together and encroaching on the valley with steep slopes gashed by ravines or covered with a growth of small timber. The bottom lands are mostly clear of trees, but in many places the stream is lined with a fringe of timber which here and there spreads out into the flats. The valley walls are lined along parts of their extent by gravels which outcrop in numerous exposures. Porter creek likewise is noteworthy chiefly for its gravels, which will be described later.

It may be said here that practically all the streams of the county have one characteristic in common. They all flow through alluvium-filled valleys. This is true of all the larger streams, and even many of the small ravines show some filling in their side walls and floors, due chiefly to lateral wash. But all, from the Boyer to the merest runnel, are now cutting into this filling and flow in deep trenches, and consequently the secondary and tertiary tributaries have cut gashes in their valleys many of which are deeper than their width. In some cases this cutting has gone through the filling into the original drift material, as is shown in a small gully in the northwest quarter of section 33, Stockholm. Drift is exposed along nearly the entire length of the gully and the black filling is distinctly marked off from the yellow till below. Many of these streamlets drop nearly three hundred feet in their short courses and so have great erosive power.

These facts seem to indicate an increase in cutting power, of the smaller streams at least. It may be that the larger streams have not experienced any change, or not so much as their tributaries. If this is true the cause of the change in these small streams must be local. Probably one factor has been the cultivation of the soil, the cutting of timber from the hillsides, the consequent lowering of the water level and other effects of the progress of agriculture and pasturing. These changes would aid in the washing of soil from the hillsides to the valleys and by the increase and concentration of the runoff deeper incision of the ravines would be possible.

West Nishnabotna River.—Southeastern Crawford county, including Iowa, most of Hayes and Nishnabotany and parts of East Boyer and Washington townships, is drained by the upper branches of West Nishnabotna river. The eastern of the two branches barely touches the county as it cuts across the two southeastern sections of Iowa township. With its tributary, Elk creek, it carries the surplus waters from nearly all of this township. As developed in this county the river is but a small stream flowing in a shallow trench. The flood plain is nearly a fourth of a mile wide and is bounded on both sides by very gentle slopes reaching back in some cases one-fourth to one-half mile before they meet the uplands. The topography is all so rolling, however, that exact limits can not be set. The stream is here so high —see elevation of Botna, 1290 feet, just beyond the county margin—that its valley is comparatively shallow, only about one hundred and fifty feet below the upland ridges.

The west branch of West Nishnabotna rises in eastern Hayes township and in western Washington township of Carroll county. It has a general southwesterly course across Hayes and Nishnabotany townships past Manilla. Like the east branch this stream has a wide valley with very gentle slopes and even in the eastern part of Hayes it shows some flood plain. This is wider toward the south so that in northeastern Nishnabotany township it is a quarter of a mile wide owing to the merging here of several small streams. Below this point the alluvial plain is well marked although the boundary walls are everywhere of low slope and descend to the plain very gradually. The river winds back and forth across this plain, though with quite a swift current and considerable fall.

The members of this system as found in Crawford unite in Shelby county to form the West Branch of West Fork Nishnabotna river which unites with the East Fork in Fremont county. The combined stream empties into the Missouri in Atchison county, Missouri.

Soldier Rivers.—That part of Crawford county west of the territory tributary to the Boyer is drained by the several branches of Soldier river and Willow creek. The general features of these streams and their valleys are similar to those just given for the Nishnabotna. There are three branches of the Soldier, Soldier river proper, much the largest, Middle Soldier, only a short stream, and East Soldier. They may be said to receive the waters of the four northwest townships of the county. The main fork extends diagonally across Soldier township, which it enters from Ida county, the southern townships of which county send most of their waters to the Missouri by this stream. Its chief auxiliary in Crawford is Beaver creek, which extends across the northern sections of Morgan township. At the headwaters of Beaver creek, as well as of the other streams of the region, the bordering slopes are quite steep. But lower down the slopes are more gentle and grade easily up to the country beyond. The valleys are not very deep and all, barring the smallest, have flat bottoms and well defined alluvial plains, narrow in the upper courses but wider where the streams are of greater importance. Beaver creek has a flood plain almost entirely across Morgan township and that of Soldier river is well defined across all of its course in Soldier township.

Middle Soldier shows the same type of shallow valley and gentle slopes as those which characterize the main branch. West of Ricketts it has developed a flood plain which unites with that of East Soldier at the county line. The two streams join their waters just beyond the line, in Monona county, and the united stream meets that of the main Soldier just west of Ute. The gathering grounds of Middle Soldier are entirely surrounded by those of Beaver creek and East Soldier, hence the growth of this branch to the east is strictly limited.

East Soldier rises on the flanks of the divide southwest of Schleswig and in its general course is only two to three miles distant from the middle branch. Its valley is quite broad and shallow with very gently sloping sides as may be seen by inspecting the accompanying figure 47. For example the road along the north line of section 23, Charter Oak, rises only forty feet in the half mile from the river east to the section corner. However, the ridge road across central Hanover rises nearly three hundred feet above the river at Charter Oak, so that the total relief is, after all, high. The stream gradient also is fairly gentle as is shown by the fall of forty-five feet between the middle of section 7, Hanover, and the north line of section 23, Charter Oak, an average of about eighteen feet per mile. This is, probably, a fair average for the river in this county. In a number of places the valley is narrowed by ridges, hardly level enough or large enough to be classed as benches, which run down from the higher level into the valley.

There is not much flood plain east of the Charter Oak town-

FIG. 47.—View north across East Soldier valley from the divide in the southeast quarter of section 15; Hanover township.

ship line but below here it is quite broad and well defined. For the most part the stream follows the south edge of the valley and has cut into its south bank at a number of points.

The chief tributary of East Soldier is Emigrant creek, which enters the larger stream at Charter Oak. It is of the usual type of stream. The Chicago, Milwaukee & Saint Paul Railway utilizes the valley of this creek for its line, which rises 115 feet in the four miles between Charter Oak and the divide which separates Emigrant and Paradise creeks.

Willow Creeks.—The branches of Willow creek, North, Middle and South, are of only small import in our country. They do not differ in character materially from the Soldier and their effect on the topography is similar. As is true of other headwater streams of the county their fall is gentle except at the immediate heads, and the same holds good for their laterals. The middle branch, for example, falls seventy-five feet from the north line of section 23, Willow, to where the combined streams leave the county, an average of about fifteen feet per mile. The Willow creeks are far from their master, the Missouri, and hence are not cutting very rapidly. But just over the divides are some laterals of Boyer river which are vigorous swift flowing streams in steep sided valleys and surrounded by rough rolling uplands. It must be kept in mind, however, that the natural erosional effect of these systems of streams has been somewhat masked by the excessive deposition of the Missouri river loess, whose topographic features are discussed under the caption of Topography.

North and Middle Willow creeks have but little alluvial bottom lands except near their junction just within the county line. But in their cross sections they show to good advantage the characteristic broad flattened curve, concave upward, rising to the hills where it meets the convex curves of the uplands.

Areas of Drainage Basins.—The area of Crawford county is apportioned among its different drainage systems about as follows: Boyer basin, 429 square miles; Nishnabotna system, 113 miles; Soldier river basin, 146 miles; and the Willow rivers 32 square miles, a total of 720 square miles.

STRATIGRAPHY

General Summary

The formations exposed within Crawford county carry its history back through only the last two epochs of geologic time—the Pleistocene or Glacial and the Recent. While as viewed from the standpoint of human history the Pleistocene epoch seems a long one, stretching back as it does over hundreds of thousands and possibly several millions of years, yet as compared with the vast lapse of earth history this epoch is but a span. And yet it is certainly of the utmost importance to us for the deposits of that epoch are our soils and sands and gravels today. The Recent Epoch may be said to be practically co-extensive with the period of human history, although there is evidence to show that man existed, in Europe and Asia at least, during the later interglacial ages of the Pleistocene epoch.

For any knowledge of the underlying strata we must rely on those wells which have penetrated the deposits of Pleistocene or later age and have reached or entered the indurated rocks beneath. Within the county there are but few such wells and only one which pierces to any great depths these hidden strata. Outside the county a large number of wells in western Iowa have been sunk to great depths. Those nearest to Crawford county are at California Junction, Dunlap and Holstein. The strata which these penetrate and the probable relations of these strata in Crawford county will be discussed beyond.

The succession of the deposits exposed within the county is shown in the following table.

Synoptical Table.

Group	System	Series	Stage	Character
Cenozoic	Quaternary	Recent		Alluvial and aeolian deposits
		Pleistocene	Wisconsin	Alluvium ? Sand and gravel
			Peorian	Loess
			Iowan Sangamon Illinoian	Gravel
			Yarmouth	Soils and peat Kansan Gumbotil, Gravel
			Kansan	Drift
			Aftonian	Soils Nebraskan Gumbotil
			Nebraskan	Drift

Underlying Formations

As stated above no deposits older than the Pleistocene are exposed within Crawford county. A few wells have been sunk to the rock or a few feet into it and the city well at Denison penetrated the rock formations to the Prairie du Chien (see the table on page 301). Mr. Frank Hoffard of Arcadia reports that the King well, in section 9, Hayes township, altitude of curb 1450 feet, penetrated a rather coarse gray sand rock for twenty-two and one-half feet. The well ends in this rock at a depth of 572½ feet. A well on the farm of McCaffery Brothers in the south half of section 29, Jackson township, whose curb is about 1500 feet above sea level, struck a very hard yellow limestone at 305 feet. The well continues in rock to a depth of 662 feet, giving a penetrated thickness of rock of 357 feet. The Miller well, in section 16, Milford, beginning at 1422 feet above sea level, struck, at a depth of 462 feet, a blue-gray limestone, which it penetrates thirty feet. The Franklin well in section 17, East Boyer, altitude of curb 1317 feet, reached a very coarse sandstone at 390 feet and is sunk into it for the remainder of its depth of 404 feet. It will be observed that the two southern wells are in sandstone, the two northern ones in limestone. The elevations of these wells as given above would place the top of the rock at approximately 900 feet at the King well, 1200 feet at the McCaffery well, 960 feet at the Miller well and 930 feet at the Franklin well. Rock was struck in the Denison well at an altitude of 970 feet beneath 200 feet of unconsolidated material. The rock is chiefly shale. These wells give some indication of the irregularity of the rock surface and of its lack of relationship to present day topography.

The list of typical wells given in the report on the underground water resources of Carroll county[25] includes the Shrower well, two miles east of Arcadia, which, sunk from a probable elevation of about 1425 feet, struck sandstone at 360 feet and penetrated it forty feet. The Anderson well five miles northeast of Arcadia, and the Eklers well, six miles south of the same town, are both 400 feet deep and reached sandstone or cemented sand. These wells must end at about 1050 and 1025 feet above sea respectively. Mr. Hoffard reports that in the Hanerkamp well, in section 22, Arcadia township, he struck "rock" at 375 feet and drilled 37½ feet into it. The rock surface here probably stands at about 1050 feet above sea and the rock is doubtless sandstone, as in the Shrower well close by.

25 W. J. Miller, Iowa Geol. Survey, vol. XXI, p. 1026; 1912.

It may be admitted that these wells furnish slight basis for a judgment as to the age of the rocks which they enter. Such judgment must be based also upon our knowledge of other wells and of the strata in other localities. Limestone is exposed in Boyer valley at Logan and is reached at Woodbine twenty-eight feet below the surface. Doctor Shimek assigned the rock at these and several other localities in Harrison county to the Missouri series partly because of the character of the rock itself, partly on the basis of a collection of fossils obtained by Doctor Calvin from Logan.[26] However, Doctor Tilton has more recently presented an elaborate argument for considering these strata to be of Des Moines age. Tilton draws the north border of the Missouri series about the latitude of Atlantic in Cass county. He claims that the fossils found at Logan are of Des Moines facies rather than Missouri.[27] The lithologic character of the beds exposed at Logan and reached in several wells in Harrison county is more like that of the Missouri strata than that of the Des Moines beds as they are exposed in the Des Moines valley. However, it must be remembered that if the beds in the two regions are contemporaneous limestone might be forming in the deep sea to the west while shale and coal were forming along the shore in the Des Moines valley region. The strata penetrated in the Cox well near Missouri Valley, as recorded by Shimek, may at least be correlated with the Des Moines series as readily as with the Missouri series. This record is as follows:

	FEET
Surface material, clay, etc.	144
Limestone, in layers of 3 to 9 feet	36
Coal	3
Rock (record not definite)	97
Soft coal	3

Another well which perhaps should be mentioned here is that at Onawa, nearly due west of Denison, in Monona county. It is 863 feet deep, has an altitude at the curb of 1054 feet and penetrates 130 feet of valley filling, 150 feet of alternating shale and

26 Iowa Geol. Survey, vol. XX, pp. 301-303.

27 Tilton, John L., Missouri Series of Pennsylvanian System in Southwestern Iowa: Iowa Geol. Survey, vol. XXIX, pp. 310-312. See also The Strata near Stuart, Iowa; Bull. Geol. Soc. America, vol. 33, p. 153.

sandstone and thence limestone to the bottom with some shale at 350 feet. Perhaps the alternating shale and sandstone belong to the Des Moines series. The limestone at 300 feet is assigned to the "base of the Pennsylvanian."[28]

The deep well at Denison penetrates a series of shales which extend from a depth of 200 feet to 480 feet. They are chiefly gray with blue, chocolate-colored and black variations. Fragments of coal are present in the sample from 360 feet, and limestone is mixed with shale from 380 to 410 feet. This assemblage has quite a marked Des Moines appearance.

In the case of the sandstones penetrated in Hayes and East Boyer townships and in the wells near Arcadia in Carroll county there must be considered the possibility of a Cretaceous age. Doctor Bain assigned without any doubt the sandstones of Carroll county to the Cretaceous, both those which outcrop along the Raccoon and those which are reached by wells near Arcadia. Probably this disposition need not be questioned so far as the exposures along the Raccoon are concerned although if we are to classify the other strata discussed above as of Des Moines age we must also take into account the possibility that the sandstones reached by the wells in western Carroll and eastern Crawford counties likewise belong to the same series. The geological maps of Iowa represent the Cretaceous deposits as extending over all of the area here discussed but it is well known that as a matter of fact the actual distribution of these deposits is very patchy. Their exact extent can not be accurately mapped on account of the thick mantle of glacial drift. Hence it is quite possible that the Cretaceous beds have been eroded away from the areas where these wells are located. One argument in favor of the Des Moines age of these sandstones is their relatively low altitude—900 to 930 feet above sea level in Crawford county while those near Arcadia are about 1100 feet above sea. The exposures of Cretaceous beds in southeastern Carroll county are about 1165 feet above sea level, and those in the northeastern part of the county have an altitude of about 1140 feet. While we can not place great confidence in these figures on account of the irregular

28 Miller, W. J., Underground Waters of Monona County: Iowa Geol. Survey, vol. XXI, pp. 1054-1058.

erosion of the preglacial surface it seems only reasonable to assign the sandstones of Crawford county, with some degree of doubt, to the Des Moines series.

One other well in the county may reach rock. This is the well of Mrs. Mary Herring in the southeast quarter of section 18, Otter Creek township. It is 410 feet deep and the lower twenty feet is in "soapstone." The elevation of this well is about 1500 feet above sea level, hence the rock surface, if rock is reached, is in the vicinity of 1110 feet above sea level. The Benton shales of the Cretaceous outcrop on Middle Raccoon river near Auburn, Sac county, at a similar elevation, and this "soapstone" may belong to the same body, although of course, it may be merely very fine-grained glacial clay or perhaps it belongs to the Des Moines shales. If the latter is the case the Cretaceous strata must be eroded away. These wells are discussed in more detail on pages 352 to 354.

ARTESIAN WELLS

The city well at Denison is the only one in the county which pierces the indurated rocks to any great depth. It is sunk to a depth of 1810 feet from an altitude of 1170 feet, in the East Boyer river bottoms. An excellent set of samples was collected by the city engineer, Mr. Frank Woolston, and a record of these as examined and interpreted by Dr. W. H. Norton is given below.

Record of strata in City well No. 1, Denison.

	DEPTH IN FEET
Pleistocene and Recent, 200 feet thick, top 1170 feet above sea level.	
Alluvium, silts, clay and glacial tills; 20 samples	10-200
Pennsylvanian, Des Moines (?), 170 feet thick, top 970 feet above sea level.	
Shales, gray, brown, black; fragments of coal at 360; 17 samples	210-370
Mississippian, Devonian (?), Silurian, 780 feet thick, top 800 feet above sea level.	
Limestone, whitish and light yellow gray, crystalline-earthy, rapid effervescence in cold dilute HCl, in flaky chips, with some chips of black shale	380
Flint, yellowish; limestone of same color; a little shale	390
Limestone, buff and gray, fine-grained, effervescence moderately slow	400, 410
Shale, gray, calcareous, in concreted masses	420, 430
Chert, white; limestone, gray; some brown ferruginous limestone; shale in concreting powder	440
Shale, gray; with some limestone, white crystalline-granular and light yellowish, cryptocrystalline, rapid effervescence; white chert	450
Shale, gray; limestone, white, gray and buff, rapid effervescence; chert, chalcedonic silica and quartz sand in fine irregular grains; 3 samples	460-480
Limestone, gray, fine crystalline-granular; much blue-gray flint	485
Flint, blue-gray, and limestone, yellow-gray and whitish, crystalline-granular, rapid effervescence	490
Limestone, whitish and yellow-gray, rusted buff, encrinital, rapid effervescence	500
Limestone, blue-gray and whitish, subcrystalline and earthy, rapid effervescence; at 520 laminated and with chips of vein or geodic quartz; 4 samples	510-540
Limestone, light yellow-gray, calcilutite, and buff, fine crystalline-granular	550
Limestone, light yellow-gray, whitish and gray, crystalline-earthy and fine crystalline-granular, oölitic at 580, cherty at 570 and 690; rapid effervescence, with considerable quartz sand in cuttings at 610 and 630, and some in all; 14 samples	560-690
Limestone, light yellow-gray, effervescence moderately slow, some rapid	700
Limestone as above, cherty; 3 samples	710-730
Limestone, light yellow-gray, fine-grained, rapid effervescence; light gray chert	740
Limestone, drab, cherty, argillaceous, rapid action in HCl	750
Limestone, light buff, fine crystalline-granular, rapid effervescence, cherty	760
Limestone, buff, rather slow reaction to acid	770
Limestone, light gray, rapid effervescence	780
Dolomite, light blue-gray, fine crystalline-graular, in fine sand; 4 samples	790-820
Limestone, gray, earthy, rather rapid action in acid, some chips slow	830
Dolomite, light blue-gray; 3 samples	840-860
Dolomite as above, with some limestone chips of rapid effervescence	870
Dolomite, light yellow-gray, fine crystalline-granular with some chips of rapid effervescence, 5 samples	880-920
Dolomite, light gray, somewhat argillaceous	930
Limestone, whitish and blue-gray, earthy, in flaky chips, rapid reaction to acid; some dark gray, finely laminated, highly argillaceous; some green shale, fissile, calcareous	940
Dolomite, light buff	950
Shale, blue gray, highly calcareous, in hard concreted masses	960

Dolomite, light yellow-gray, cuttings unwashed, in friable concreted masses, washed cuttings in crystalline sand	970-980
Dolomite and shale; dolomite, light yellow-gray, in sand; shale blue-gray	990-1000
Dolomite as above, some flakes of gray green shale; in hard concreted masses	1010
Dolomite and shale; dolomite, light yellow-gray, in sand; shale in concreting powder	1020
Dolomite, in light buff sand; 4 samples	1030-1060
Dolomite, light yellow-gray and buff, crystalline-granular, effervescence somewhat more rapid than Le Claire dolomite; at 1100 majority of grains of cuttings show rapid effervescence; 9 samples	1070-1150
Ordovician	
Maquoketa shale, 40 feet thick, top 20 feet above sea level.	
Dolomite, blue-gray, earthy, moderately slow reaction; and shale, dolomitic	1160
Dolomite, dark blue gray, moderately slow, in sand; shale in powder, considerable pyrite	1170
Shale, light drab, in hard concreted masses gritty with fine limestone particles	1180, 1190
Galena and Platteville, 480 feet thick, top 20 feet below sea level.	
Dolomite, buff, subcrystalline, considerable pyrite at 1220; 3 samples	1200-1220
Chert, white, gray and blackish, mottled; and dolomite	1230
Dolomite and chert as above	1240
Chert and dolomite, light gray	1250
Dolomite and chert	1260
Dolomite, light gray, 3 samples	1270-1290
Dolomite, gray, vesicular, crystalline-granular, rough, cherty	1300
Dolomite, gray and dark gray, subcrystalline, and white chert; some cuttings with pepper and salt appearance. 8 samples	1310-1380
Dolomite, gray, argillaceous; cherty	1390, 1400
Dolomite, light gray, with flint of same color	1410
Dolomite, whitish, in flour, argillaceous, cherty, with particles of crystalline quartz too minute to polarize in strong colors	1420
Dolomite, gray and buff, mostly in fine crystalline sand, cherty at 1440 to 1470, 1510 to 1540; 15 samples	1430-1570
Limestone, blue-gray and yellow; gray, in small chips, rapid effervescence	1580
Shale, light blue-gray, highly calcareous, in hard concreted masses, quartzose with minute grains and angular particles; 3 samples	1590-1610
Limestone, light yellow-gray, earthy, soft, rapid effervescence, in flaky chips; and chips of green-gray, fissile calcareous shale	1620
Shale, blue-gray, green-gray and drab, calcareous; 4 samples	1630-1660
Limestone, light gray, rapid action with acid; pyrite, chips of gray shale	1670
Saint Peter sandstone, 60 feet thick, top 500 feet below sea level.	
Sandstone, white, fine grains well rounded, frosted; a few chips of limestone of brisk effervescence at 1680; a little green shale in chips at 1710-1720; 5 samples	1680-1720
Sandstone, minute ill-rounded grains of pure quartz, some stained with iron; chert; much pyrite	1730
Prairie du Chien, penetrated 80 feet, top 560 feet below sea level.	
Dolomite, whitish, light yellow-gray and pink, somewhat rusted, sparsely arenaceous with imbedded grains; cuttings in coarse sand with considerable quartz sand and green shale	1740
"Drillings washed away"	1750-1760
Dolomite, light gray, and oölitic chert	1775
Dolomite, light yellow-gray, in sand, arenaceous, particles of dolomite largely in excess of quartz grains	1785
Dolomite as above, some quartz grains with secondary enlargements	1795,1805
Dolomite, as above, arenaceous, grains of quartz sand, rounded, coarser and more numerous than above; considerable chert	1810

NOTES

In the Denison section the Coal Measures may seem exceptionally thin, but it must be taken into account that their base lies 45 feet higher than at Audubon, for example, of points southeast, while the preglacial surface stands 88 feet lower.

The base of the Mississippian is undetermined. If it lies about the same distance above the top of the Saint Peter as at Audubon, it may occur at 780 feet (390 feet above sea level) where dolomites or magnesian limestones begin in heavy beds.

The thickness of the Silurian at Stuart, where it is believed to be marked by gypsiferous beds, leads to the inference that the dolomites at Denison from 790 to 1150 feet may belong to that system. The shales and argillaceous limestones at the latter depth seem to correspond stratigraphically with the Maquoketa at Stuart. The underlying dolomites and limestones and basal shales to the Saint Peter sandstone at 1670 feet are thus assigned to the Galena and Platteville.

The Saint Peter is here too fine of grain to be a bountiful water-bed. The main supply comes from the creviced dolomites and sandy layers of the Prairie du Chien. The upper beds of these dolomites, and perhaps all of them, belong to the Shakopee, but possibly the highly arenaceous stratum struck at 1805 represents the New Richmond sandstone.

It may be added that the cuttings were unwashed. The colors given are those of the individual chips after washing and are thus different from the color of the cuttings in mass, which was pretty uniformly a gray.

Driller's Record of Denison Well.

262 feet of 14 inch hole, cased with 14 inch pipe.
10 inch hole to 1618.6 feet, cased with 10 inch pipe, 261 feet long to 500 feet, overlapping 14 inch and swaged.
8 inch hole 1618.6 feet to 1810 feet. Cased with 46 feet, 6 inches of 8 inch casing from 1618.6 feet to 1665 feet, over shale.
Struck shale at 245 feet.
"Drift" and shale to 485 feet.
Brown limerock to 950 feet.
Lime rock with traces of shale to 1600 feet.
Shale and rock to 1665 feet.
Lime rock to 1680 feet.
Sand rock to 1730 feet.
Brown lime rock to 1810 feet.
Numerous crevices in this lower part, 1730-1810, also most water in this part.
Not a great deal of water from 1680 to 1730.
In hard rock.

In the table below are given summaries of the strata penetrated by the Denison well and also by a few others in neighboring counties, together with other information of interest. The Holstein well is sunk from the upland; the others are on the lowland and therefore do not represent the full thickness of the Pleistocene.

Table of Elevations of top of Strata and Thickness of Strata in Wells at:[29]

	Holstein (No. 2)		Denison		Dunlap		California	
		Feet		*Feet*		*Feet*		*Feet*
Altitude of curb	1457		1170		1151		1010	
Altitude of bottom	–583		–640		–384¾		–450	
Depth of well	2040		1810		1535¾		1460	
Formations penetrated	Altitude	Thickness	Altitude	Thickness	Altitude	Thickness	Altitude	Thickness
Pleistocene and Recent	1457	420	1170	200	1151	225	1010	122
Cretaceous (?)	Absent		Absent		926		Absent	
Pennsylvanian	1037	170	970	170	?	307	888	342
Mississippian	867	140	800		619	288		
Devonian	Absent ?		?	780	331		546	663
Silurian	Absent ?		390?		?	715¾		
Ordovician	727	900	20	660	?		–117	333
Maquoketa	Absent ?		20	40	?		–117	55
Galena-Platteville	727	700	–20	480	?		–172	278*
Saint Peter	27	20	–500	60	–366?	18¾*?		
Prairie du Chien	7	180	–560	80*				
Cambrian	–173	350						
Jordan (?)	–173	10						
Saint Lawrence and undifferentiated	–183	340						
Algonkian (?)								
Red clastic beds	–523	40						
Archean ? granite	–563	20*						

* Well ended in this formation.

The table gives a fair idea of the range in character of the strata in western Iowa, although it will be noted that there is much conjecture as to the thickness and limits of some of the beds. There are some surprising variations in the strata which perhaps are to be explained by differential erosion or possibly by differences in deposition, as well as by the natural dip of the rocks. Holstein, the most northerly of the towns here listed, is seventy miles northeast of California, the most southerly of the four, and thirty-four miles northwest of Denison. Dunlap is eighteen miles southwest of Denison and California is about thirty miles southwest of Dunlap. The table shows how unevenly the beds dip and how irregular are their thicknesses in the short distances between these towns.

The rock level is shown at a number of other localities near

[29] The Holstein Well No. 2 is described somewhat in An Unusual Well Record in Northwestern Iowa: James H. Lees, Proc. Ia. Acad. Science, vol. XXX, pp. 445-450; 1923. Doctor Norton has kindly furnished his determinations of the complete set of samples from the new Holstein well for reference in making this table. The record of the Denison well as given here and on pages 298 to 300 is taken from Doctor Norton's determinations. For details regarding the Dunlap well see, W. H. Norton, Underground Water Resources of Iowa: Iowa Geol. Survey, vol. XXI, p. 1131; 1912. The California record is summarized from the driller's log and from records of the drillings made by Doctor Norton and the writer.
The Holstein, Denison and California wells will be described by Doctor Norton in volume XXXIII of these reports.

Crawford county and some of these may be enumerated. Low water in the Missouri at the Blair railroad bridge west of California is 986 feet above sea level. Rock was reached in borings at a depth of forty-five feet or at 941 feet above sea level. The altitude of the railroad station at Missouri Valley is 1,006 feet and wells sunk here reach rock at ninety feet—916 feet above sea level. The station at Logan is 1,035 feet above sea level. Rock is found in the river bank rising sixteen to eighteen feet above low water in Boyer river, that is 1,000 feet or more above tide. At Woodbine limestone occurs twenty-eight to thirty feet below the surface of the flat along the Chicago and North Western railway, which lies at 1,058 feet. This places the rock surface about 1,030 feet above sea.[30] At Arcadia, according to Bain,[31] the altitude of the sandstone is about 1,100 feet, and Mr. Frank Hoffard, who has drilled wells in that vicinity, also states that it lies about 300 feet below the surface. The railway station is 1,387 feet above the sea.

The altitude of the rock surface at Odebolt is about 1100 feet, according to Bain. He states, however, that wells go down 350 feet in drift, and this is borne out by the record of the city well at Odebolt. Since the elevation of the town is about 1360 feet and it is near the divide, the rock surface would seem to be about 1000 or 1050 feet above sea level. A well sunk in section 10, Jackson township, in our county, penetrates the drift to a depth of 500 feet without striking rock. The rock here must be 1,000 feet or less above sea. Some holes near Manilla are sunk 300 to 515 feet in drift. This again places the rock surface at 1000 feet or below. Mr. W. A. Davie has sunk wells in Boyer and Union townships to depths of 235 to 270 feet entirely in drift. As these wells are near the upland they probably do not approach the rock nearer than 200 feet, as rock was reached at an altitude of 926 feet in the deep well at Dunlap, and at 970 feet at Denison.

The Pleistocene

The table of formations given on page 294 shows that there are within the county deposits representing three glacial ages and

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30 Shimek, B., Iowa Geol. Survey, vol. XX, pp. 301-303.

31 Iowa Geol. Survey, vol. IX, p. 75. On page 77 Bain puts the surface of the rock at 1290 feet, but this seems very high. The lower figure is more consistent with other data.

at least three interglacial ages. Only the first two glaciers, the Nebraskan and the Kansan, covered the territory which is now Crawford county. The Illinoian glacier, which followed the Kansan, was too far away to affect our region directly, as it advanced only a few miles west of Mississippi river. Recent studies by Carman show that the Iowan glacier extended into Sac county but did not reach Crawford county. The Wisconsin glacier approached within a few miles of the county's northeastern bounds and Boyer valley evidently formed one of the main outlets for the waters from the ice front, as large quantities of sand and silt are spread over its floor and some of these may be traced to the Wisconsin boundary at Wall Lake.

The three interglacial ages which are represented are the Aftonian, the Yarmouth and the Peorian. In addition there is the long period representing the Illinoian and Iowan glacial ages and the intervening Sangamon interglacial age during which the everyday erosive and depositional activities of Nature were in practically uninterrupted operation in our territory. The materials which represent these interglacial ages are gumbotil, gravel, sand, soils, peat and loess. Gumbotil, it may be explained, is a gray to nearly black clay of very fine texture and with very few pebbles and these of types extremely resistant to decay, chiefly quartz. When it is wet gumbotil is very sticky and gummy, even more so than the ordinary pebbly drift clay or till. When it is dry gumbotil is crumbly and somewhat starchlike in structure. Gumbotil is the residuum from the chemical alteration of the drift clay which has resulted in the dissolution and transportation of all those parts which are soluble in water and in the weak acids formed in soils and elsewhere by natural processes and carried in ground water. Consequently all the lime is gone, most of the pebbles and bowlders are decayed and the whole mass of the drift affected has suffered profound alteration. We have no way of knowing how much of the drift has been altered in this way but gumbotils fifteen feet thick have been found at different places in Iowa, so we are certain that at least that thickness of drift was altered. Of course it was the upper part of the layer of drift which suffered these changes and there is a gradual but still rather abrupt change from the gray noncalcareous gumbotil downward through a pebbly drift clay oxidized to a yellow color and leached of its lime to the yellow limy unleached drift clay below. This change in most cases takes place within one to five feet. The unleached and unoxidized drift may be found below this yellow drift wherever erosion has progressed far enough to cut away all of the yellow portion and expose the blue or gray drift beneath. It will be evident that where a gumbotil has a pebbly limy drift clay overlying it and a similar one below, it must be derived from the one below but must be older than the one above. This fact can often be used in determining the age of a gumbotil and of the drifts underlying or overlying it.[32]

It must be understood that while the gumbotils found in Crawford county were formed during interglacial times and hence are classified in the table as Aftonian and Yarmouth nevertheless because they were derived from the alteration of glacial drifts they must be called Nebraskan gumbotil and Kansan gumbotil respectively.

In the course of his studies of the drifts and gumbotils of western Iowa Doctor Kay has found a number of excellent outcrops in Crawford county and has kindly given his notes to the writer for use in preparing this report.

THE NEBRASKAN AND AFTONIAN STAGES

Most of the exposures of deposits of Nebraskan and Aftonian age within the county fall naturally into two groups, both of which are in the eastern part of the county. The more extensive group is found in a series of cuts along the new line of the Chicago, Milwaukee and St. Paul Railway between Manning in western Carroll county and Manilla in southeastern Crawford. The other group is found along Boyer valley and its tributaries in the northern part of the county. Additional outcrops have been seen in road cuts in the southeastern townships and a few are known also from northwestern townships.

In the road between section 6, Jackson township, Crawford county, and section 31, Levey township, Sac county, a gully has

32 For original descriptions of the gumbotil the reader is referred to the following papers by George F. Kay. Some Features of the Kansan Drift in Southern Iowa: Bull. Geol. Soc. America, vol. 27, pp. 115-117. Reprinted in Iowa Geol. Survey, vol. XXV, pp. 612-615. Gumbotil, a New Term in Pleistocene Geology: Science, N. S., vol. XLIV, Nov. 3, 1916. Reprinted in Iowa Geol. Survey, vol. XXVI, pp. 217-218. The Origin of Gumbotil, George F. Kay and J. N. Pearce: Jour. Geol., vol. XXVIII, pp. 89-125, 1920.

been cut by storm waters and has exposed the following materials:

		FEET
2.	Till, Kansan, yellow, calcareous in lower part; pebbly, with some bowlders a foot or more in diameter; no loess above, lower surface irregular but in general fairly horizontal. Exposed in gully..........	0–6
1.	Gumbotil, Nebraskan, black, coarsely blocky, sticky; only very few small pebbles seen, these being one-eighth to one-fourth inch in diameter. A few small lime concretions. Contact with No. 2 irregular but very sharp, may be detected within less than one inch by acid test as well as by color. Exposed to floor of gully....	6

This exposure is on the west side of Boyer valley, about fifty feet west of the Chicago and North Western railway track. A

FIG. 48.—The Nebraskan gumbotil overlain by Kansan till in the road-cut between Sac and Crawford counties. Note how the Kansan stands with nearly vertical edge while the gumbotil surface has a decided slope.

part of it is shown in figure 48. The floor of the gully is practically at the same elevation as the railway track, or about 1235 feet above sea level. The same sequence may be seen along the railway track about one hundred yards below the road crossing. Here the gumbotil rises five feet above the track and is overlain by yellow pebbly calcareous Kansan till, while the gumbotil is not responsive to acid. The underlying strata are not exposed to view.

A little brook crosses the south part of the southwest quarter of section 11, Stockholm, extending from west to east and joining Porter creek just at the northern outskirts of Boyer village. About one-fourth mile up the valley of this brook the stream has cut into its south bank and exposed a very interesting section which is as follows (see also fig. 49):

		FEET
5.	Soil	1
4.	Till, Kansan, yellow, pebbly; calcareous below, and with some gray streaks in the lower foot	5
3.	Gumbotil, Nebraskan, noncalcareous, very dark gray, almost black, very sticky when wet, starchy fracture; some sand grains	5 1/2
2.	Clay, Nebraskan, sandy, some pebbles; shows intermingled patches of typical dark gray gumbotil and lighter gray, more sandy till. This clay is noncalcareous in the upper part but is slightly calcareous in the lower part. It grades into the overlying and underlying beds	5 1/2
1.	Till, Nebraskan, mingled gray and yellow, pebbly, calcareous; lower three feet dark blue-gray; to water level	11

The presence of typical Kansan till above the gumbotil fixes the age of the latter as Nebraskan. A few small pebbles one-

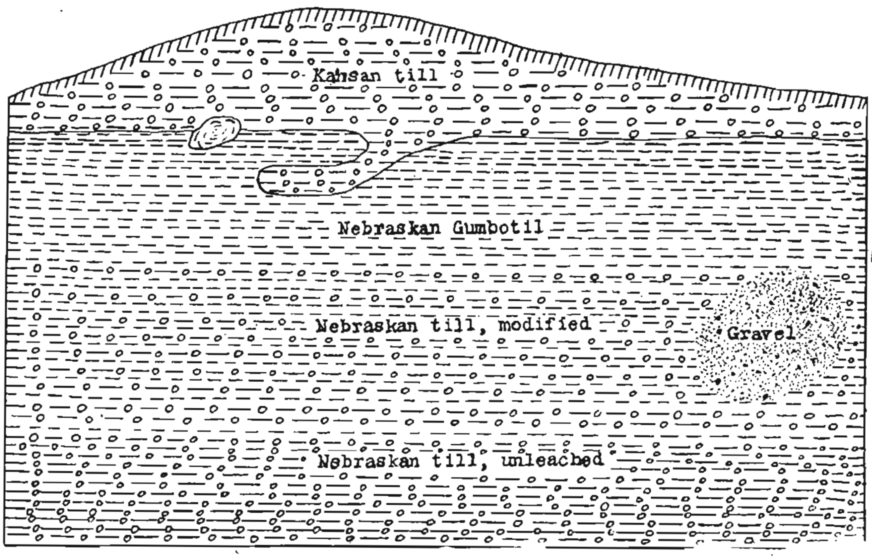

FIG. 49.—Section of the exposure of drift materials in the ravine northwest of Boyer, in the east half of the southwest quarter of section 11, Stockholm township.

eighth to one-fourth inch in diameter, which were seen on the surface of the gumbotil, most probably belong with this member and one polished pebble one-half inch in diameter was picked out of this clay. A few lime concretions were found in the lower part of the gumbotil and must have been deposited from ascending or descending waters. The contact of the Kansan till with the Nebraskan gumbotil is very abrupt and may be differentiated within an inch. Just at the contact is a gneissoid bowlder two feet long and fifteen inches high which is embedded about equally in the two strata. It is completely disintegrated except for a thin lens at the center and may be cut easily with the hoe. Below this bowlder is a layer of gray limy clay one-half to one inch thick which helps to preserve the outlines of the rock. At the center of the exposure a tongue of yellow calcareous till extends from the base of the Kansan downward and to the left a distance of about three feet, and is here overlain by a foot of gumbotil. At the right end of the exposure is a large mass of gravel which is overlain by the gumbotil and otherwise is enclosed by Nebraskan drift, as if it had been a gravel bowlder picked up in frozen condition by the Nebraskan glacier. The altitude of the top of the gumbotil is about 1270 feet above sea level.

For the sake of comparison a count was made of pebbles from the two tills. Pebbles from the Kansan till were gathered from the surface above the Nebraskan gumbotil. Pebbles from the Nebraskan till were dug out of the bank to insure the exclusion of any pebbles which might have slid down from higher levels. A few of the granites and greenstones and limestones in the Nebraskan till are so decayed that they may be cut through readily but most of these rocks appear fresh and hard. The results of the pebble count were as follows:

Nebraskan		*Kansan*	
Limestone	46	Limestone	36
Greenstones	20	Greenstones	31
Granites	14	Granites	13
Quartz	9	Quartz	6
Chert	4	Chert	4
Quartzite	2	Quartzite	4
Sandstone	2	Sandstone	1
Greenstone schists	2	Greenstone schists	5
Feldspar	1		
	100		100

There is but little difference in composition shown here. The preponderance of limestone in the Nebraskan till is not surprising, since when the Nebraskan glacier advanced over the preglacial surface it found only a residual covering rather than the thick glacial mantle which was present when the later glaciers covered our state. Hence it would be easy for the glacier to pick up a large amount of limestone. The igneous rocks in the Nebraskan must have been brought from central or northern Minnesota or still farther north, in Canada, as there was at that time no source of supply nearer the present resting place of this material. This implies a long journey beneath and within the ice. The Kansan ice-sheet may, of course, have accumulated part of its load from the Nebraskan drift.

A small gully one hundred feet east of this exposure shows the Nebraskan gumbotil with calcareous Kansan till above and calcareous Nebraskan till below.

Nearly a mile north of this exposure on the west side of the railway track just south of the bridge over the highway between sections 2 and 11 a low cutting reveals about four feet of yellow weathered Kansan drift, which is calcareous in its lower part. Beneath it is a gray Nebraskan gumbotil which for the most part shows no lime reaction with acid although in places a slight effervescence is noted. It is about four feet thick and grades down into yellow calcareous Nebraskan till which is exposed for six feet above the ditch. The surface of the gumbotil slopes to the north and within twenty-five feet the entire section as given above is replaced by loess. The Kansan till is replaced midway in the section by an eighteen inch stratum of sand upon which the loess overlaps. The elevation of the gumbotil here is about 1280 feet, or ten feet higher than that of the gumbotil exposed in the ravine a mile to the south. This difference is probably due to irregularities of the surface rather than to a general dip. It is worthy of note that in the two exposures described above the gumbotil lies at about the same altitude as the gumbotil in the Chicago Great Western railway cut east of Carroll—1270 feet.

About midway between the two exposures just described Porter creek has cut into the bluff along whose base it flows and has revealed a section which rises perhaps forty feet to the railroad track. Most of this space is occupied by sand and gravel, but the lower thirteen feet is occupied by a black sticky joint clay, the upper two feet of which is oxidized to a mixed buff and blue-gray. This extends below the level of the stream, which here is about 1225 feet above sea level, or practically fifty feet below the gumbotil exposed to the south and the north. Above the railroad track the sands rise to the surface of the ground except for a veneer of loess, hence there is nothing except stratigraphic position on which to determine the age of this till. However, its position certainly lends force to the argument that it is Nebraskan and it is here so classed. It was formerly thought that one of the characteristic features of Nebraskan till was its black color and starchy fracture. But subsequent investigations have shown that not a great deal of reliance can be placed on physical structure or composition in determining the age of the older drift sheets. In the last analysis stratigraphic relationship must be the decisive factor. Along the road on the south line of section 16, Stockholm township, on the hillside west of the creek, at an elevation of 1285 feet, there is shown two feet of gray noncalcareous sticky clay with some sand grains. Above it is five feet of yellow pebbly till and then yellow loess. Also below the gray clay there is yellow till. The upper till clearly is Kansan, the gray clay is Nebraskan gumbotil and the lower till is Nebraskan.

Kay has recently found and examined two exposures of Nebraskan gumbotil which may be added to the series just described. One of these is in the southeast quarter of section 22, Stockholm, along the road between Deloit and Boyer. Kay speaks of it as "a remarkably fine outcrop and one which will be exposed for many years." Twenty feet of oxidized till is exposed below the gumbotil and several feet of oxidized Kansan till lies above it. The gumbotil is 1255 feet above sea level.

The other exposure is one-eighth mile south of Tucker creek on the road between sections 25 and 26, Stockholm. Oxidized and unleached Kansan till with concretions and sand and gravel pockets overlies the gumbotil and forms a sharp irregular contact with the latter. The gumbotil itself contains many concretions and has been plowed by the Kansan ice. It lies 1285 feet above sea level and is about eight feet thick.

Another outcrop of Nebraskan gumbotil is exposed at an elevation of 1275 feet in the northwest quarter of section 23, Stockholm.

A much more extensive series of exposures of Nebraskan drift and gumbotil is to be found along the Milwaukee railway between Manning and Manilla. In 1913 the Railway Company changed the grade of its line across central Iowa and in so doing made a number of deep cuts which have revealed a great deal regarding the Pleistocene history of Iowa and the Mississippi valley. The cuts in the region we are discussing give sections of the loess, the Kansan gumbotil, the Kansan drift, the Nebraskan gumbotil and the upper part of the Nebraskan drift. Some of

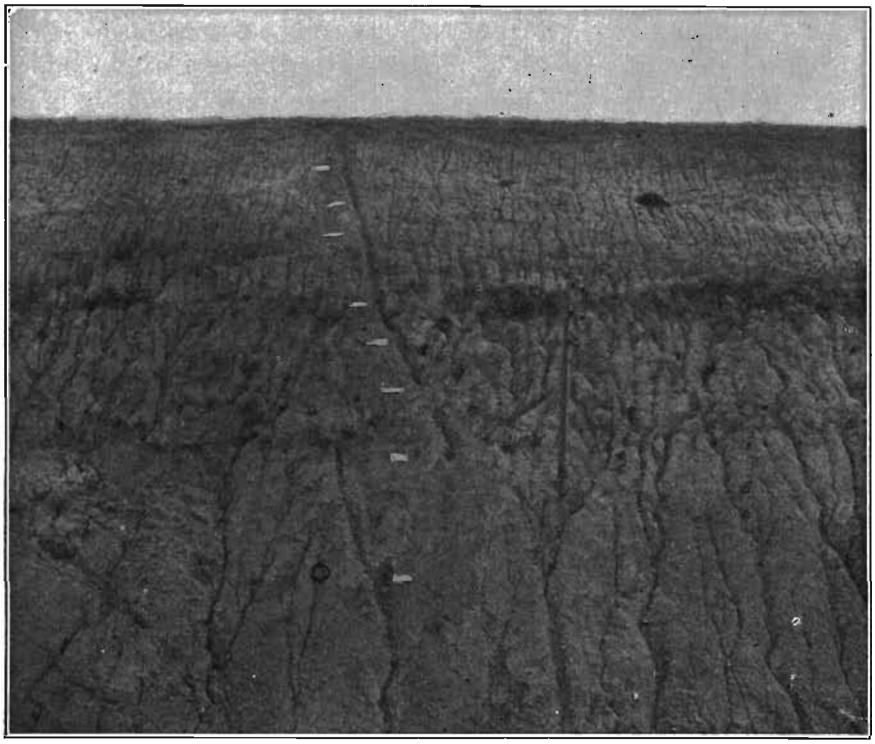

FIG. 50.—The cut along the Milwaukee railway just east of the viaduct one and one-half miles west of Manning, in the southwest quarter of section 18, Warren township, Carroll county. The cut shows from the surface the loess, Kansan till, soil band, Nebraskan gumbotil and Nebraskan till. Photo by Kay.

these sections as well as others farther east have been described in these reports[33] and some of the typical ones which include the Nebraskan deposits will be described here.

One of the best of these cuts and indeed one of the most complete sections of the Pleistocene deposits in western Iowa is just east of the county line viaduct over the railway and therefore is in the southwest quarter of section 18, Warren township, Car-

[33] Kay, George F., Pleistocene Deposits Between Manilla in Crawford County and Coon Rapids in Carroll county, Iowa: Iowa Geol. Survey, vol. XXVI, pp. 213-231; 1917.

roll county. The section exposed on the south side of this cut is described by Kay as follows. It is illustrated in figure 50.

		FEET
6.	Loess	
	Leached, yellowish gray on dry surface, yellowish brown to buff-brown on damp surface; no shells or concretions	7
	Unleached, lighter colored on dry surface than the leached loess, and when damp is buff with gray streaks. Contains shells and concretions	5
5.	Drift (Kansan), yellow, unleached, with calcareous concretions; numerous pebbles including granites, quartzites, etc. Below the oxidized, unleached drift is gray drift with a few pebbles. It is gumbotil-like but effervesces freely. It was probably picked up from the gumbotil zone below	5
4.	Soil band (Aftonian) containing carbonaceous material	1/3
3.	Gumbotil (Nebraskan), gray to drab, few pebbles. The upper six feet is fine-grained, gray and is less sticky and gumbotil-like than the lower seven feet, which is leached, but has some calcareous concretions	13
2.	Drift (Nebraskan), oxidized, apparently leached but has calcareous concretions, upon which are films of manganese dioxide	2
1.	Drift (Nebraskan), unleached, oxidized, light yellowish on dry surface, mottled brownish with gray when damp; many calcareous concretions, especially in upper ten feet	17

The surface of the lower unleached part of the loess is covered with small lichens which give it a gray tint. It seems as if the lichens must need lime for their growth. This unleached loess thins to east and west and its upper surface is parallel with the present surface of the hill. The concretions in the Kansan till are especially abundant in the upper part, as if they had been carried down in solution from the overlying material, which was leached and then eroded away before the loess was deposited. The clay below the five feet of typical Kansan till has a thickness of about three feet. At its base is six inches of light gray laminated clay without pebbles or concretions.

The contact of the different members of this section is decidedly unconformable. This is shown in part by the fact that at the ends of the cut the loess comes down over the Nebraskan till. The Kansan till and the Nebraskan gumbotil were cut away in the development of the preloessial topography. The irregularity of the succession is further shown by the north face of the cut, where, east of the crest, the loess is eighteen feet thick and is yellow and leached, but still fossiliferous, in its upper part, while the lower part is gray and calcareous. Below the loess is a pebble band and then gray gumbotil, which lies on a four foot layer of finely sandy laminated clay. Beneath this is the Nebraskan till. Just west of this point eight feet of yellow unleached Kansan till underlies loess and overlies Nebraskan gumbotil. There is here no soil band and there are no mixed layers such as underlie the Kansan till on the south face. The elevation above sea level of the track in this cut is about 1392 feet, consequently the top of the gumbotil is about 1425 feet above sea level.

A mile west of this cut, near the southwest corner of section 13, Iowa township, Crawford county, another deep cut shows at the east end about thirty feet of loess of which the upper six feet is reddish and leached and that below is buff. The lower part of the cut is covered by slump and may be in drift. The loess here bears horizontal iron bands and calcareous plates which because of their superior hardness stand in relief on the face.

A little farther to the west in the cut the loess is about twenty feet thick and beneath it is seen eight feet of yellow Kansan till and then ten feet of gray gumbotil which extends to the bottom of the grade. At the middle of the cut is the following exposure:

		FEET
7.	Loess, mixed gray and yellow with red spots; leached, grades down within two feet into next member	8
6.	Loess, buff, unleached, fossiliferous	18
5.	Drift, Kansan, yellow, unleached, oxidized, reddish near the top. The upper part carries many concretions and here pebbles of limestone, quartzite, granite, etc., are so abundant as to form a pebble band. In places a two to six foot bed of sand lies at the top of the drift	17
4.	Soil, Aftonian, gray to black, grading into lower member	2
3.	Clay, gray, fine-grained, modified gumbotil	5
2.	Gumbotil, Nebraskan, typical, medium gray, starchy structure; exposed	3
1.	Slump, to railroad level	10

When this cut was newly opened it showed ten feet of gumbotil and modified gumbotil and a few feet of underlying yellow pebbly Nebraskan till. The gumbotil as then examined is described as being very hard to pick and containing some sand grains and pebbles. At one place, above the black soil band there was exposed six feet of light blue-gray horizontally laminated clay which probably was a deposit from waters in front of the Kansan glacier. The top of the gumbotil is level almost the entire length of the cut nearly to the east end where it breaks off and the younger formations come down over it. Here the gumbotil is overlain directly by the blue clay, which is pebbly but yet not like typical till. Over it is the bed of sand mentioned above, which may have been blown up from lower levels after the development of the Kansan topography. The elevation of the track here is 1410 feet.

About two hundred yards west of the public road in the southeast corner of section 14 is another cut which shows the normal succession of loess, Kansan till, Nebraskan gumbotil and Nebraskan till. Adjoining this cut on the west, and just west of the "station one mile" post east from Aspinwall, is another cut

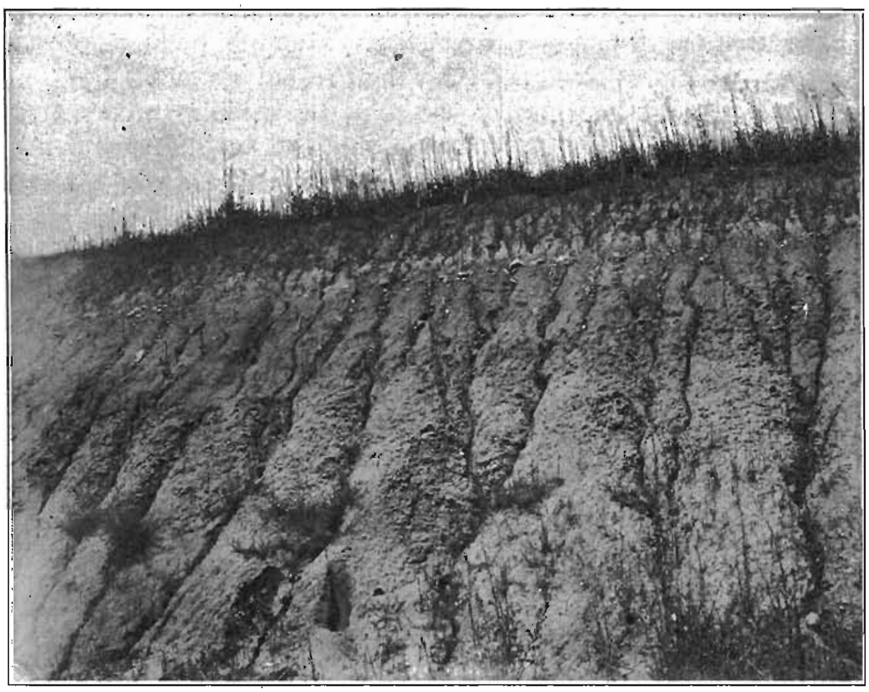

FIG. 51.—Cut in the Milwaukee railway just west of the "station one mile" post east of Aspinwall. The section shows loess, Kansan till, Nebraskan gumbotil and oxidized Nebraskan till. Photo by Kay.

which while not so deep as some, reveals several interesting features. The north side of this cut is described by Kay and is illustrated in figure 51.

		FEET
5.	Loess, yellow	4
4.	Pebble band on which is about one foot of leached loesslike clay with small pebbles	
3.	Drift (Kansan), oxidized and leached	4
2.	Gumbotil (Nebraskan), gray, sticky, starchlike fracture, some concretions	5
1.	Drift (Nebraskan), oxidized, in lower part calcareous; exposed	5

It is evident that much weathering of the Kansan drift materials had transpired before the deposition of the loess, for the reddish concentrate above the pebble band evidently represents the residuum of the Kansan gumbotil while the underlying pebble zone represents the residuum from the Kansan till, which is here very thin and wholly leached. Another interesting feature is the fact that the Nebraskan till is calcareous within a foot of the base of the gumbotil. Still another noteworthy character is the thickening of the loess down the slopes of these cuts, which shows that the preloessial topography was one of more abrupt contours and steeper slopes than the present surface.

The south side of this cut shows at the middle three feet of yellow loess which is concretion-bearing and fossiliferous below, then three feet of brownish sticky noncalcareous Kansan till with decaying granites and other pebbles, then light gray sticky Nebraskan gumbotil which shows the usual starchy structure and contains very few pebbles. The top of the gumbotil is 1420 feet above sea level.

A section about half a mile west of Aspinwall, in the northwest quarter of section 15, Iowa township, is of interest because the basal exposed member, the Nebraskan gumbotil, of which only

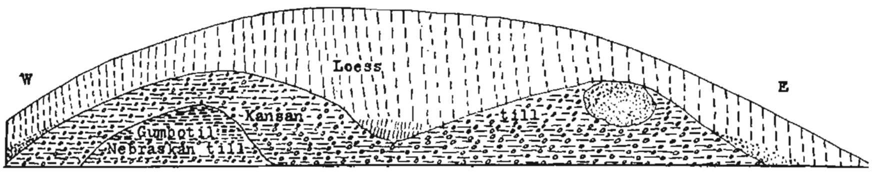

FIG. 52. Diagram of the cut along the Milwaukee railway, two miles northeast of Manilla in the northeast quarter of section 13, Nishnabotany township. Note the two knolls of Kansan till.

four feet appears above the railroad grade, is only about 1395 feet above sea level, twenty-five to thirty feet lower than in the cuts east of Aspinwall. The gumbotil rises as a low dome near one end of the cut and is covered by Kansan till. This section will be described in detail in the discussion of the Kansan stage, on page 324. The only other cuts of this series which show Nebraskan materials are two in section 13 of Nishnabotany township. One of these is in the northeast quarter and is peculiar in that the Kansan till rises in two knolls beneath the loess. It is shown diagrammatically in figure 52. The valley between is filled with drab loess. The upper part of the loess is brownish yellow and the entire body is here twenty-five feet thick. When the cut was opened there was exposed in the north wall a large sand pocket which extended to the top of the old preloessial hill. Bedded sand also overlaps the till beneath the loess, rising upon both slopes of the old hill. Beneath the Kansan till is eight feet of gumbotil of which the upper two or three feet shows some effervescence, owing probably to the mingling of the Nebraskan gumbotil with Kansan till. Four feet of leached yellow Nebraskan till is exposed beneath the gumbotil. The Kansan till is unleached throughout its thickness and carries concretions all through its mass. The altitude of the top of the gumbotil is about 1380 feet.

The other cut, in the southwest part of the section, shows the same succession but the gumbotil is here eroded away until only about three feet remains. The altitude of the gumbotil must be not far from 1370 feet.

The exposures of Nebraskan materials previously mentioned as being found in the northwestern part of the county were seen by Doctor Kay. One of these is about an eighth of a mile east of the southwest corner of section 14, Otter Creek township. It shows from above downward: oxidized Kansan till, 11 feet; drab to gray Nebraskan gumbotil with concretions, 8 feet, at 1375 feet altitude; and oxidized unleached till with a narrow upper leached zone, 5 feet.

In the northwest quarter of section 20, Morgan, about one-fourth mile south of the highway bridge, a little stream has exposed the following section, as described by Kay.

		FEET
4.	Loess	
3.	Till, Kansan, oxidized, pebbly; in lower part gray, unoxidized, unleached	5
2.	Gumbotil, Nebraskan, gray on dry surface, dark to drab on moist surface; a few pebbles and concretions; some shells; dark organic matter in upper part. Elevation, 1360 feet	8
1.	Till, Nebraskan, oxidized, brownish, unleached; gray where least oxidized	5

Another section found by Kay in this part of the county is in the northwest quarter of section 34, Hanover, and shows oxidized unleached Kansan till above Nebraskan gumbotil.

One of the most interesting exposures of Pleistocene materials in the county is in the northeast corner of section 23, Soldier township, and was discovered by Kay. Here, about two hundred yards southwest of the corner of the section, a little stream has cut into its bank and laid bare a most unusual series of materials. The section as described by Kay is as follows:

		FEET
5.	Loess	4
4.	Till, Kansan, pebbly, unleached, mostly oxidized; gray where unoxidized	16
3.	Peat, Aftonian, consolidated into distinct layers	1/12 to 1/2
2.	Silts, dark gray to drab, highly calcareous and containing many shells, except in upper foot, which is leached	7
1.	Till, Nebraskan, oxidized, highly calcareous and with many concretions, gray to bluish where least oxidized. Bed of stream is unoxidized and unleached till	3

The peat lies 1355 feet above sea level and evidently accumulated in a depression on the Nebraskan gumbotil plain. It is exposed for twenty yards along the stream.

One of the noteworthy features of this series of exposures is their elevation, which ranges from 1355 to 1400 feet above sea level, an average of about a hundred feet above the exposures of Nebraskan gumbotil near Boyer valley, which lie 1240 to 1280 above sea level. Either the four exposures just described must have been on eminences rising above the Nebraskan gumbotil plain or else they represent the general elevation of that plain and the exposures found in and near Boyer valley represent a depression in the plain. The evidence is not sufficiently abundant to be conclusive, but these phenomena should be considered in connection with the discussion of the elevation of the Nebraskan gumbotil plain which is given below.

Elevation of the Nebraskan gumbotil plain.—It is interesting to note the elevation of the Nebraskan gumbotil plain, both in Crawford county and in other regions where it has been examined. The surface of the gumbotil in the first section west of Manning is about 1425 feet above sea. Thence it declines to the west so that near Manilla it stands at about 1370 feet. Eastward, likewise, it is lower, for in a cut a mile west of Coon Rapids, Carroll county, described by Kay, the Nebraskan gumbotil is only about 1180 feet above sea level. To the north as we have seen in Stockholm township, Crawford county, the gumbotil lies 1240 to 1280 feet above sea level. Still farther northwestward the writer found Nebraskan gumbotil under Kansan till in the east part of section 4, Silver township, Cherokee county, eight miles south of Cherokee, in a gully tributary to Silver creek. The altitude here is about 1260 feet. Again, sixty miles east of Cherokee along Des Moines river near Bradgate the writer found beneath Wisconsin till a gumbotil which must be Nebraskan. It lies at an elevation of about 1100 feet, too low for the Kansan gumbotil. South of Crawford the gumbotil has been found in several counties. For example in Cass county, as noted by Tilton,[34] it lies approximately 1220 feet above sea level. He states further that "It appears to be higher in the northwestern part of the county than in the southeastern part." In Adams county as determined by the writer the remnants of the Nebraskan gumbotil plain now lie at about 1175 feet near Prescott, 1160 feet near Corning, 1150 feet in the northwestern part of the county and 1130 feet in the southwestern part. East of Portsmouth, in Shelby county, the gumbotil lies 1245 feet above sea level, according to Kay. Those remnants which are found in eastern Montgomery county also lie from 1110 to 1150 feet above sea level.

Farther east, in Clarke county, Tilton[35] has determined the altitude of the Nebraskan gumbotil, by the barometer, to be "at a level of about 1040 feet above sea level in the eastern part of the county, about 1113 feet above sea level in the central part of the county, and about 1156 feet above sea level in the western part of the county."

The evidence thus far in hand, then, if we exclude for the moment the three outcrops in the northwestern part of the county, seems to show that the Nebraskan gumbotil plain as it exists at present reaches its maximum known elevation, 1425 feet, in the vicinity of Manning. Thence, with the exception above noted, it seems to slope in all directions, to 1370 feet near Manilla, to 1270 feet near Carroll, to 1240 and 1280 feet near Boyer, to 1234 feet near Atlantic, to 1160 feet near Corning, to 1113 feet near Osceola. It is interesting to speculate as to the cause of this flattened dome. Was it because of a greater heaping up of Nebraskan drift in the neighborhood of Manning, or was it because Af-

34 Tilton, J. L., Geology of Cass County: Iowa Geol. Survey, vol. XXVII, p. 225.

35 Geology of Clarke County: Iowa Geol. Survey, vol. XXVII, p. 140.

tonian drainage and erosion were less effective there than elsewhere? If it is true that the gumbotil was developed before erosion had affected the Nebraskan drift plain to any great extent it seems hardly probable that later Aftonian erosion could have shaped the contour of the Nebraskan gumbotil plain. It seems most likely that the solution of the problem will have to await the accumulation of more complete and extended data.

There may arise a question as to the extent of the Nebraskan drift and gumbotil at the present surface. Of course it is impossible to know definitely where the Nebraskan is the surface drift, but it seems probable that where the streams have cut below the level of the Nebraskan gumbotil plain the lower parts of their valleys are in Nebraskan drift. This will be more likely to be true if the valleys are post-Kansan in age, as seems to be the case. If they were older than the Kansan stage the Kansan drift would, of course, fill them and would be the drift to be exposed by erosion. It is evident that this is not the case universally. Again, the Kansan drift undoubtedly fills hollows in the Nebraskan and may therefore be uncovered locally by erosion at levels lower than that of the Nebraskan gumbotil plain. All these factors make impossible a definite answer to the question as to the present superficial extent of the Nebraskan drift.

Almost equally difficult of answer is the question as to the thickness of the Nebraskan drift, because of our lack of knowledge of the elevation and character of the preglacial surface. That surface must be quite irregular as is shown by the depth to rock in the few deep wells which have reached it. For instance the Lorenson well described on page 353, which was sunk to a depth of 500 feet from an elevation of about 1500 feet above sea, does not reach rock. The McCaffery well, three miles south, sunk from about the same elevation, reaches rock at 305 feet or about 1200 feet above sea. If the Nebraskan gumbotil plain lies here at about 1270 feet as it does near Carroll and Boyer there is only about seventy feet of Nebraskan drift present at the maximum. However, all the other wells in the county which reach rock find it at much lower levels—970 feet above sea at Denison and at similar altitudes in other wells near by; possibly about 1100 feet near Schleswig. This allows a greater thickness for the Nebraskan, reckoning from the altitude of the buried gumbotil plain, a thickness which may amount to as much as three hundred feet.

Deposits of Uncertain Age.—An examination of the accompanying sketch map of Crawford county will show that most of the larger valleys are cut below the level of the Nebraskan gumbotil plain. It is at least possible, therefore, that some of the deposits exposed near the bottoms of these valleys may be of Nebraskan age. Hence a few exposures so located will be described here before we pass to the description of those materials whose Kansan age and origin are beyond question.

Where Beaman creek debouches into Boyer valley, in the center of section 6, Jackson township, there is an exposure showing ten feet of till which is blue-black at the base, yellow and blue-gray above. While as before indicated but little reliance can be placed on physical characters in distinguishing Nebraskan from

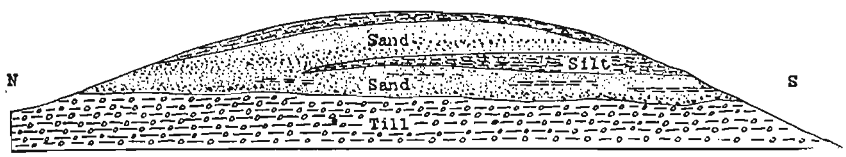

FIG. 53.—Diagram of a cut along the Illinois Central railway two miles south of Deloit, in section 24, Goodrich township.

Kansan till, yet this till is darker than is most of the Kansan till exposed in this region. This, with its position, gives plausibility to the suggestion that it may be Nebraskan. Above it lie sand and silt beds nine feet thick with a foot of soil overlying them. There are similar exposures of blue-black till along Trinkle creek which while it is at somewhat higher altitudes may possibly be Nebraskan in age. In the northwest quarter of section 2 of Stockholm township Porter creek has cut into its west bank and has exposed eight feet of till which is almost black near water level and is bluish gray to yellow above. This till is similar to that exposed a mile down stream as described on page 308.

The Illinois Central Railroad Company has made several cuts along the east wall of Boyer valley but little above the level of the floor. One series lies between Brogan and Ells and another is between Deloit and Denison. The best of these cuts is the first one north of Denison and is located in section 24 of Goodrich township. It shows the following section, which is illustrated in figure 53:

		FEET
5.	Clay, pebbly, yellow, or clayey sand	2
4.	Sand and gravel bed, fine, yellow in lower foot, coarser above, particularly just above the lower fine layer	5
3.	Silt, sandy, gray, in lenslike layer; pinches out to north and No. 4 overlaps No. 2	4
2.	Sand, fine, yellow, some clay streaks, coarser below, where some cobbles are six to eight inches in diameter	6
1.	Till, black or dark gray, sticky, small pebbles, starchy fracture, forms water table for seepage springs; exposed	12

Number 1 may be Nebraskan till while the overlying members probably belong to the gravel series discussed on pages 328 to 338.

On the west side of Boyer valley between Deloit and Denison is a group of natural exposures which are of interest as showing well the character of the materials in which the lower part of the valley is cut. One of these, a gully trenching the bluff about the middle of section 13, Goodrich, shows a dense pebbly till which is blue-gray below and yellowish above. It is exposed for over sixty feet above the valley floor, and is overlain by a very red sand with some clay streaks and gravel layers near the top. This sand rises to the humus. The till is abundantly bowlder-bearing, the chief types being granites, quartzites and other light colored rocks with some of the darker varieties. Again, the bank of a small stream between sections 13 and 14, Goodrich, shows, about one-fourth mile above its mouth, an interesting section consisting of a foot of soil, twenty feet of leached yellow loess, eight feet of blue-gray loess with shells and concretions, ten feet of sand and gravel, four feet of fine gray silt, and ten feet of dense, tenacious blue-black pebbly till to water level. A somewhat similar succession may be seen at the mouth of the creek valley, between the bridges, and at several other points along the river valley wall as far as Denison. Below here outcrops of till are but few and indecisive. An outcrop, similar to those described above, is found up Buck creek, however, in the southwest quarter of section 8, Washington. This outcrop extends from the railway bridge over the creek one hundred feet up stream and reveals a total of eight feet of stiff, pebbly blue-black calcareous till which is overlain by silts and sands, over which in turn lies abundant loess.

Common characteristics of these exposures are the very dark color of the till, its tenacity and the fact that in most cases it is overlain by nothing more determinative than sand, gravel, silt and loess. In other words, if we lay no stress upon physical characters there is nothing but topographic location to aid in determining the age of the deposits. They all lie below 1200 feet above sea level or but little above that altitude, well below the probable elevation of the Nebraskan gumbotil. In view of the irregularity of the surface of the much eroded Nebraskan gumbotil plain when it was covered by the Kansan glacier it is not possible to affirm to which of the two drift sheets which have covered the area of Crawford county the exposures mentioned, as well as others in similar locations, belong.

THE KANSAN AND YARMOUTH STAGES.

With the exception of the area possibly covered by Nebraskan drift as discussed in the preceding paragraphs the uppermost drift the county over is the Kansan. Of course it is almost everywhere covered by the loess and so it can be rarely observed, except upon hillsides and in other localities where natural or artificial cuttings bring it to view. The Kansan till of Crawford county is similar in character to that found elsewhere—it is oxidized to yellow or even to red in its upper parts and is gray or blue-gray below. It is pebbly except in the leached portions where the pebbles have been dissolved away, and it is quite markedly bowlder-bearing, the number of quartzites being especially noticeable. Like the Nebraskan drift it has had developed in its upper parts a sheet of gumbotil—the Kansan gumbotil. It used to be thought that Nebraskan and Aftonian time was longer than Kansan and Yarmouth time and this indeed may be true. Nevertheless it seems to be significant, as pointed out by Doctor Kay, that whereas the average thickness of Nebraskan gumbotil is between eight and nine feet, the average thickness of Kansan gumbotil is more than eleven feet. Of course erosion following the development of the gumbotils introduced a time factor of unknown value, but at least it seems likely that the period of gumbotil formation was longer in Yarmouth than in Aftonian times. It may be that the period of erosion was longer during Yarmouth time, but we have no measure of this in our region as erosion went on here presumably without interruption from its beginnings following the formation of the Kansan gumbotil to the time of the deposition of the loess.

Yellow or reddish weathered Kansan drift is exposed along numbers of the hillsides and steep slopes of the eastern and southern townships where the loess blanket is not too thick for the underlying formations to be revealed. In some cases the fresher, unleached, more or less unoxidized till is revealed, as along Tucker creek in the northwest quarter of section 30, Jackson, where the basal part of a fifteen foot outcrop is bluish with reddened bands along joints. On the other hand some exposures show the upper part of the till changed to a red pebbly ferretto, as where the public road crossed the old line of the Milwaukee railway on the west line of section 13, Iowa, where it appears as a very hard compact band under gray loess.

Naturally the best exposures of Kansan till and overlying materials are those made where the railways trench the uplands. Here again the best series of cuts are those along the "High line" branch of the Chicago and North Western railway between Boyer and Schleswig and those along the Chicago, Milwaukee and St. Paul railway between Manning, Manilla and Buck Grove. Along the High line there are several cuts north of the one showing Nebraskan gumbotil which reveal the ordinary succession of yellow till with loess or ferretto and some in which a bed of gravel or sand is intercalated between till and loess. A long cut just west of where the railroad curves to the west shows above the slump an old hill of yellow very pebbly Kansan till with uneven surface on which is spread two feet of fine yellow sand with a thin pebble zone between. Over the slope of the old hill lies twenty feet of yellow fossiliferous loess.

The cut on this line which parallels in interest the one exposing Nebraskan gumbotil is in the region where the railroad crosses the divide between Boyer river and Otter creek. Here it reaches an altitude of 1400 feet or over and the uplands rise to 1450 feet above sea. This cut is in the northwest corner of section 9, Stockholm. It shows above the railroad track the following section:

		FEET
3.	Loess, yellow, leached except in the lower six inches	5½
2.	Gumbotil, Kansan, gray to dark, chocolate-colored to red at the top; fine-grained, starchy structure, very sticky when damp, few pebbles, a yellow sandy layer in basal part	3
1.	Drift, Kansan, leached and reddened in upper foot and a half, lime balls in lower unleached part	6

The upper part of the gumbotil is what Doctor Kay has called the gumbotil concentrate, a resultant of the further weathering of the gumbotil. It is remarkable how thin the zone of transition from gumbotil to unleached till is—only one and one-half feet. This is a general condition and seems to argue for great resistance of the till against leaching. The base of the gumbotil forms a practically horizontal plane and both gumbotil and till were cut away by erosion until steep slopes were formed. Over these slopes the veneer of loess was later deposited, in a relatively thin layer at the top and on upper slopes, in thicker beds on lower slopes, thus toning down the steep declivities of the later Yarmouth and subsequent topography.

Kansan drift is exposed again at the railroad bridge over Otter creek where it shows a bowlder band at the contact with the overlying loess, indicative of a large amount of preloessial erosion. A few cuts between Kiron and Schleswig show drift beneath loess, but owing to the greater thickness of the loess toward the west drift exposures are but rarely encountered. This is true of all the western townships and as here the railways follow the streams there are very few opportunities presented to study the till in this region. A few of these which are observable may be noted because of the characters they present. A dark blue-black till is exposed in a stream-cut along the north line of section 9, Soldier. It grades up into blue-gray and then into yellow till. Almost at the county line along the road on the north line of section 30, Soldier, where it rises from Soldier valley, is an exposure of very rusty clayey sandy residual material under the loess. A road-grading on the south line of section 32, Morgan, near the church, cuts into the top of an old Kansan hill and exposes beneath the loess a very hard rusty red pebbly ferretto. A small knoll on the east wall of Middle Soldier valley opposite Berne shows a gravelly till with pebbles as large as three or four inches in diameter. A short distance north of Ells is a cut on the Illinois Central railway showing thirty feet and gravel, which probably was picked up by the glacier from of till, which lies underneath and on either side of a mass of sand the frozen gravels at its foot. Some of the exposures seem to make it plain that the Kansan till had undergone great alteration and weathering before it was protected by the blanket of loess.

One of the best series of exposures of the Kansan till and gumbotil is that to be seen along the line of the Chicago, Milwaukee and St. Paul railway between Manning and Manilla and that between Manilla and Buck Grove. Some of the cuts along the former line have been discussed already under the Nebraskan. One of these, which was mentioned on page 314, may be de-

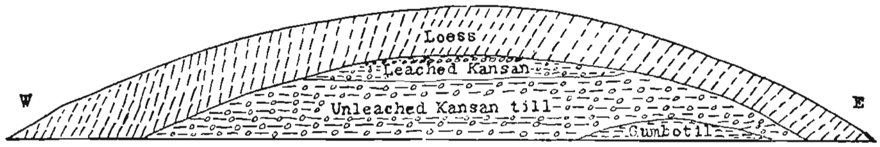

FIG. 54.—Diagram of a cut along the Chicago, Milwaukee and St. Paul railway one-half mile west of Aspinwall, in the northwest quarter of section 15, Iowa township.

scribed in detail here. It is in the northwest part of section 15, Iowa township, half a mile west of Aspinwall, and shows very well the stages of weathering through which the Kansan till has passed. On the north side of the cut the section is as given below. A diagram of the face is shown in figure 54.

		FEET
5.	Loess, gray, covering entire section	10
4.	Concentrate from Kansan till or gumbotil, with thin pebble band at base	1
3.	Till, Kansan, leached	3
2.	Till, Kansan, unleached, some lime concretions	20
1.	Gumbotil, Nebraskan, gray, exposed only for fifty feet in east part of cut, rising above railroad track	4

The gumbotil lies at an altitude of about 1390 feet, and it seems remarkable that the concentrate zone of the Kansan till should be such a short distance above it. This section in connection with the one next to be described seems to show some irregularity in the surface of the original Kansan plain. The section also is most illuminating in its revelation of the course of Pleistocene events. It shows that after the development of the Nebraskan gumbotil the surface was eroded and carved into an irregular topography; that later the Kansan ice overrode the gumbotil plain, covering it with its sheet of drift; that after the disappearance of the Kansan ice the Kansan drift was subjected to intense weathering until the upper part was changed into a practically insoluble residuum and the part immediately below was entirely leached of its lime content. Following this period of weathering there ensued a time of more active erosion, during which the Kansan gumbotil, which doubtless was originally present here, and the leached Kansan till were cut through in places and locally even the fresh unleached Kansan till was deeply trenched with the resultant formation once more of a markedly irregular surface, although the crests of the newer hills were not in all cases coincident with those of the older eminences. After the post-

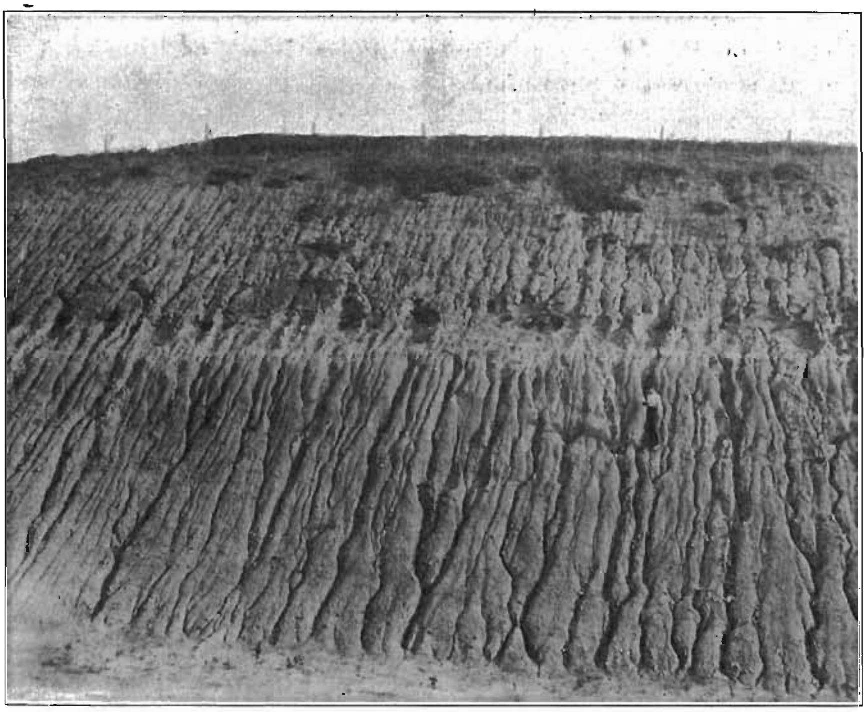

FIG. 55.—Divide cut on the Milwaukee railway between Manilla and Aspinwall. The cut shows loess, Kansan gumbotil and Kansan till. Photo by Kay.

Kansan topography had come to a stage of maturity the whole surface was blanketed with a veneer of loess, which has had the effect of protecting it, in large part at least, from further erosion or weathering.

A mile farther west, in the southwest corner of section 9, is a cut which shows a further stage in the erosion of the Kansan plain. Here there is, under ten feet of loess which is gray and calcareous below and brownish above, an exposure of twenty-five feet of yellow till which is calcareous and concretion-bearing to the base of the loess. There are traces of a pebble zone at the contact of drift and loess, but there is no gumbotil and no brown leached zone at the top of the till. The railway grade here rises to the highest point between Manning and Manilla—1428 feet—hence there is no doubt of the Kansan age of the till.

The divide cut between Manning and Manilla is about the middle of section 8, Iowa, and shows the best section of the Kansan deposits to be seen along this line in Crawford county. It has been described and illustrated by Kay on page 221 of the paper already cited. His description is quoted below and his view of the cut is shown in figure 55.

		FEET
4.	Loess	
	Buff, leached	12
	Buff, unleached, shells and concretions, lighter in color than the leached loess; lower part gray, but closely related to the buff loess	12
3.	Gumbotil (Kansan), dark gray to chocolate-colored	3
2.	Drift (Kansan), oxidized, leached, closely related to the gumbotil, contains disintegrating bowlders	4
1.	Drift (Kansan), oxidized yellowish to buff, unleached; abundant lime concretions, many of which are in vertical joints	17

The evidence indicates that several feet of gumbotil was eroded from here before the loess was deposited. The base of the gumbotil in this cut has an elevation of about 1440 feet above sea level, which is only about twenty feet lower than the base of the gumbotil in the Templeton cut ten miles east. In the Templeton cut fifteen feet of gumbotil was found over Kansan till.

Kay has recently found in southeastern Crawford county three exposures which are of especial interest both because of their elevations and because of the relationships of the drifts and gumbotils. One of these exposures is one-fifth mile south of the school house in the northwest corner of section 32, East Boyer, and shows eight feet of till, of which the lower three feet is still gray, unoxidized and unleached. Below the till and in sharp though irregular contact with it is gray leached gumbotil in which a few siliceous pebbles were found. The elevation of this gumbotil is 1450 feet.

The second exposure is on the south side of the road about the middle of the south side of this same section, 32, and it shows beneath fifteen feet of loess and soil a gray sticky gumbotil with chocolate colored mottlings and containing but few pebbles. This gumbotil is seven feet thick and lies at an altitude of 1485 feet. It grades down into yellow oxidized and leached till of which a thickness of three feet was exposed.

The third of this series of outcrops is about a mile east of the second, near the middle of the south line of section 33, East Boyer. It shows gumbotil-like material on till and is about 1450 feet above sea level.

It seems evident that the two lower gumbotils here described, those at 1450 feet elevation, are Nebraskan, that the till which overlies the northwestern of the three outcrops is Kansan till and that the gumbotil at 1485 feet in the middle exposure is Kansan gumbotil. The remarkable features of the exposures are the extreme thinness of the Kansan till—only about thirty-five feet—and the unusual elevation of the Nebraskan gumbotil —1450 feet, as compared with elevations of 1370 and 1385 feet near Manilla.

On the road between sections 17 and 20, Iowa township, a road cut studied by Doctor Kay is of unique importance because it shows two gumbotils on one slope. The Nebraskan gumbotil is exposed near the base of an east facing hillside and may be seen along the roadside for forty yards. No drift is exposed below this gumbotil but above it two to three feet of pebbly oxidized bowldery drift may be seen. About fifty-five feet above this gumbotil lies the Kansan gumbotil, which grades down into chocolate colored till which in turn grades into leached and oxidized till and this again into unleached but oxidized till. Over the Kansan gumbotil lies the loess. The lower gumbotil lies 1385 feet above sea level while the upper one is about 1440 feet above sea. Both gumbotils show the usual features of gray or drab color, compact texture with polygonal fracture, stickiness when damp and only a few small pebbles. No concretions were seen.

Along the Sioux City division of the Chicago, Milwaukee and St. Paul railway there are a number of cuts between Manilla and Buck Grove. Several of these show a normal succession of loess overlying till, and in some cases the upper part of the till is much weathered and is reddened almost to a ferretto, while in others the till is calcareous to the contact with the loess. The cut at the overhead bridge in the northeast part of section 20, Nishnabotany township, shows eight feet of yellow loess with ten to fifteen feet of gray loess below. The gray loess is banded by red streaks. Below the loess a yellow pebbly till rises about ten feet above the grade. This is here 1465 feet above sea level, hence there is no doubt of the till being of Kansan age.

In the northwest quarter of section 19, Nishnabotany, a cut shows four feet of dark leached loess, then four feet of gray, hard, sticky jointed gumbotil, below this four feet of leached till, of which the upper two feet is red and the lower part yellow, and at the base ten feet of yellow pebbly till. This cut is much lower than the divide cut at the viaduct—the railway is about 1400 feet above sea—but there is no reason to question the actuality of the gumbotil here.

There are several cuts west of this one which show normal yellow pebbly till and one on the east edge of section 14, Washington, presents at the top of the yellow till a layer of dark red starchy clay which evidently is nearly a gumbotil. The last important cut is in the center of this section and reveals a sand and gravel band five to ten feet thick with six feet of ferruginous much weathered till above and calcareous blue-gray till beneath. A gully below the railroad grade reveals twenty feet of gray to brown pebbly joint clay beneath the eight feet of blue-gray till seen above the grade. The railway grade is here at about 1340 feet, so it is perhaps a question whether this till may not be Nebraskan.

THE GRAVELS.

Certain deposits of sand and gravel along a number of streams, particularly those in the eastern part of the county, excite unusual interest because of their relationships. These sands and gravels line the valley walls and floors. In the former location they rise in some cases fifty feet or more above the bases of the walls.

It may be said in general that these gravels are rather fine in texture. There is comparatively little coarse material and cobbles over six inches are rarely seen. A few bowlders have been found, but most of the material is quite fine sand. Furthermore much the greater part of these deposits is clean and fresh. Very little of it is rotted or even rusted.

Probably the best known exposure is at the Mill pit at the southwest corner of Denison, in the northwest corner of section 14, Denison township. Here is exposed a face of fifty feet or more, of which nearly the whole extent is rather fine cross-bedded sand with streaks of gravel intercalated. The character of the

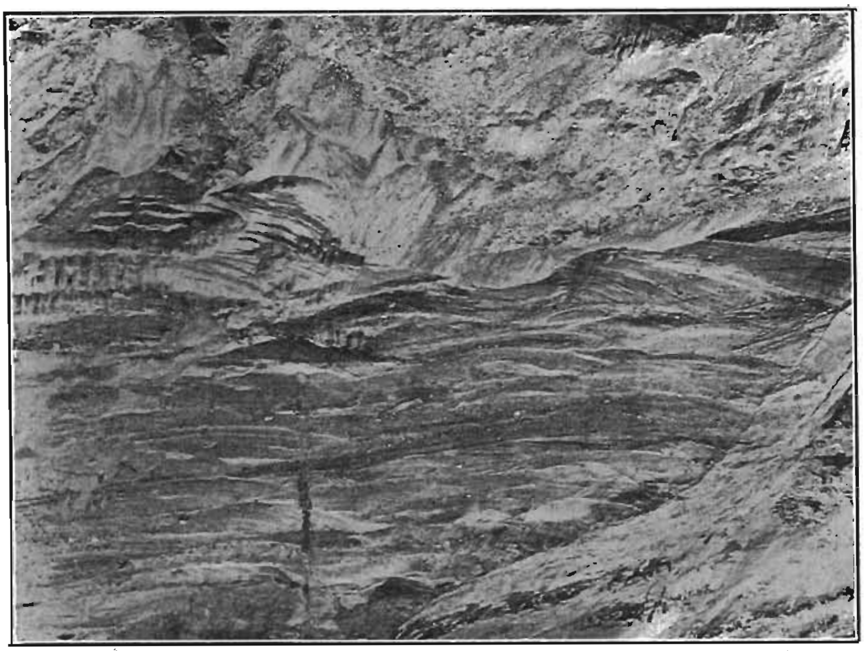

FIG. 56.—The Mill sand pit at the southwest edge of Denison. Photo by Calvin.

beds is well shown in figure 56, from a photo by Calvin. The sands are yellow, gray, and in a few places deep rust red. Above the sand is a three foot layer of yellow to brown loess in which were found shells and lime concretions as well as an elephantine rib about twenty-four inches long. Above the loess in places is a sandy loamy layer two to three feet thick. A number of mastodon teeth and other skeletal remains have been found in the sands of this pit and have given rise to some interesting speculations as to the age of the deposits.

Another pit which shows well the character of these valley deposits is one owned by G. McAhren of Denison. It is in the northeast corner of section 13, Goodrich, and showed at one time eight feet of cross-bedded gravel with irregular streaks of sand. This layer grades down into fine cross-bedded sand with intercalated layers of gravel. About fifteen feet of this lower bed is exposed. The gravels are not very coarse; very few pebbles are six inches in diameter. Some of the upper gravel layers are blackened by manganese dioxide while a few are reddened with iron oxide, but most of the material, coarse or fine, is clean gray or yellow. An older opening shows above the gravel four feet of loess, of which the upper half is yellow and contains abundant lime concretions, and the lower half is gray and calcareous and carries fossil shells and iron pipestems. The contact of loess

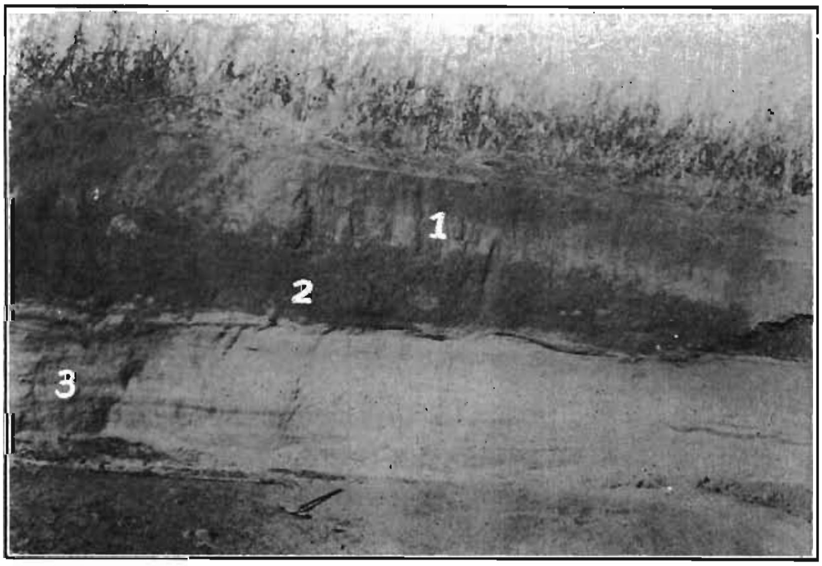

FIG. 57.—The Riddell gravel pit in the northeast quarter of section 3, Union township. The view shows yellow loess (1), gray loess (2), and gravel (3).

and sand is very irregular; indeed the two are intermingled in bands and masses and there are locally slopes along the contact which are as high as thirty or forty degrees. The sand and gravel must have been in the form of a knoll when the loess mantled them.

These two pits give a very good idea of the character of these gravels and sands. Similar deposits may be found along Boyer valley at intervals from Boyer to Dunlap, but it will be sufficient to mention a few localities. Among these are some of the cuts along the Illinois Central railway between Ells and Deloit and several between Deloit and Denison; openings at several points near Denison; a large pit at the mouth of Buck creek operated by the Milwaukee Railway; several pits between Arion and Dow City, particularly the Riddell pit just below Arion (Fig. 57) and the Butler pit across the valley; and the three small pits in section 26, Boyer township, which were described on page 267. A number of the valleys tributary to the Boyer also are lined with these gravels. Thus there is a close lying succession of benches and shoulders of gravel in Porter creek valley from near its head in southern Sac county to its mouth. Some of these deposits rise at least fifty feet above the valley floor. Similar conditions hold good in Wheeler creek valley just east of Porter creek, also in Beaman and Trinkle creek valleys, on the east side of the main drainage course. There are some beds in East Boyer valley, though these are not so common or so extensive as those in the larger valley. Among those may be mentioned a bed in the southeast quarter of section 5, East Boyer township, which has been used in road improvement and which was visited recently by Doctor Kay, who described the material as being mostly under two inches in diameter and quite fresh except near the surface, where it is somewhat oxidized and stained black with manganese oxide. Otter and Buffalo valleys north of Denison and Buck creek east of Arion have large amounts of these gravels which by their characters go far toward making clear certain parts of the physiographic history of the region.

Among the other valleys of the county in which these gravel deposits are found may be mentioned West Nishnabotna river, on which are several outcrops between Astor and the upper reaches of the east branch in southern Hayes township. One of the best is at the bridge on the Nishnabotany-Iowa township line where under fifteen feet of loess, yellow and leached above but gray and calcareous below, is to be seen three feet of coarse gravel and cobbles, including granites, quartzites, greenstones, limestones and sandstones. Several of the exposures are at the edge of the slope from the upland and hence the material has not been moved since these slopes assumed their present form. A bed of fine sand rises a few feet above the water just west of the bridge south of Astor and is overlain by twelve feet of yellow loess. A few thin intercalated streaks of sand and loess mark the contact but otherwise the gradation is abrupt.

A few gravel beds are visible along West Soldier valley, as in sections 9 and 29, Soldier, and one or two on Middle Soldier, as at the bridge between 26 and 27, Hanover. But most of the valleys in western Crawford are so heavily blanketed with loess that all other materials are concealed. For the most part these valley gravels blend with the slopes of the valley walls and hence give rise to no distinctive topographic features. In some cases, however, they stand out as narrow terraces or shoulders, as in Porter valley, or they outcrop at the edges of broad low benches, as in the case of the beds exposed in section 26, Boyer, above Dunlap. It should be noted in addition that the larger valleys at least seem to have, under the upper stratum of alluvium, a lower layer of sand and gravel. The presence of these deposits is attested by the town wells of practically every municipality which is situated in a valley and has a public water system. Doubtless these gravels are related in age and origin to those exposed along the valley sides, although some of them may be valley trains of the Wisconsin drift margin at Wall lake.

The relationships of these sands and gravels are such as to excite considerable interest. This interest is increased by the presence on the hillsides of a coating of sand and gravel beneath the loess. This coating is very commonly present and is the source of the water supply of many of the farmers who live among the hills and valleys of the county. Even the town of Schleswig, situated on the highest prairies of the county, finds a supply of water in gravels at the head of a shallow draw at the edge of town. From the fact that these gravels may be found at all elevations from on or near the hilltops almost to the valleys it seems evident that they are to be correlated with the thicker deposits found lining the valley walls and floors. The thickness of the layer is reported as ranging in different wells from two to eight feet.

Age and Origin of the Gravels.—The fact that these gravels occur in all topographic positions from the floors of the valleys to the upper slopes of the hills makes certain the deduction that they were not gathered into their present position until the Kansan gumbotil plain had been carved into a form approximating its present strong relief. This calls first for a period of downcutting following the development of the gumbotil, during which the materials eroded were being carried away from our region. Later there must have succeeded a time when erosion was so rapid that only the finer materials were entirely removed while the coarser parts—the sands, gravels, cobbles and bowlders—were concentrated on the hillsides or swept into the valleys, doubtless clogging the latter at least to the height of the present terraces and banks of gravel. This later stage of erosion implies some change in conditions which caused greater downcutting but did not permit corresponding transportation to go on. What could the processes have been which led to these results?

It is a well known fact that the Kansan drift of northwestern Iowa is quite pebbly and in addition contains large gravel masses, as Doctor Carman demonstrated during his work on the Pleistocene Geology of Northwestern Iowa.[36] Some of these now rise above the drift plain as gravel hills.

Doctor Kay has stated as one thesis of his theory of the gumbotils and the events following their formation the apparent necessity for uplifts after the gumbotils had developed on the drift plains. This would allow the erosion of the plains and the carving of valleys and other irregularities in their surfaces. In the case of the Kansan drift plain, after the development of the gumbotil there must have been a general uplift which permitted deep erosion in the Kansan gumbotil and underlying drift. Following this general erosion there must have been another uplift —this time greater in northwestern Iowa than farther south, and perhaps accompanied by climatic changes—which accelerated erosion in the parts of the state affected, but for some reason did not cause transportation to be equally effective. That this uplift was differential is shown by the fact that whereas in southern Iowa and as far north as southern Crawford county the Kansan gumbotil is present, and is locally fifteen feet thick, as we have seen, in northern Crawford it is only three feet thick and farther north it is absent. Furthermore in northwest Iowa

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36 Carman, J. E., Iowa Geol. Survey, vol. XXVI, pp. 232-445. See especially Chaps. IV and V.

the Kansan drift is in many places unleached to its contact with the loess. Both the gumbotil and the leached zone are gone. Crawford is just at the border between the thick gumbotil and leached drift of the south and the region of no gumbotil nor leached drift to the north.

Doctor Carman found that in the region studied by him—that is, north of Crawford county—practically every valley contained preloessial gravels similar to those described for Crawford county, and that these extended in many cases to the heads of the draws. There the gravels apparently were mostly swept into the depressions. In Crawford some of the gravels still remain on the hillsides. Farther south the gravels are still incorporated in the drift. In northwestern Iowa the Kansan drift has been eroded to an almost level plain while in Crawford and the southern counties the rugged type of Kansan topography is still very decidedly predominant. All these facts point to differential uplift of northwestern Iowa as the cause of the second period of erosion which still further cut away the drift and resulted in the releasing and accumulation of the great bodies of sand and gravel which are now present north of Crawford county as well as eastward to the Wisconsin drift margin. There do not seem to be many nor extensive beds of sand or gravel in the valleys south of Crawford county. The waters which carried the wastage into the valleys evidently were not of sufficient force to carry the coarser parts much farther south.

It is a fact perhaps worthy of mention here that these gravels are found indifferently in valleys extending in any direction. Thus the writer found them in abundance in the valley of Brushy creek, a branch of South Coon flowing southeast across Carroll county, as well as along Silver creek, which flows northward from near Holstein to join Little Sioux river below Cherokee.

It is plain then that the formation of these gravel and sand beds occurred long after the retreat of the Kansan ice-sheet from this region. Was it during Yarmouth interglacial time, or during the period when the Illinoian ice-sheet lay across southeastern Iowa, or during the Sangamon interval, or while the Iowan glacier was covering northern Iowa? Was the upwarp caused by the melting away of the ice and the lightening of the load on the land? It is impossible at present to answer these questions although the series of events between the recession of the Kansan ice and the formation of the loess required so much time that it seems probable that the circumstances we are discussing here may have occurred after the close of the Yarmouth, long as that time was. The upper time limit, of course, is marked by the deposition of the loess, which is considered to have taken place very soon after the Iowan ice was melted back, that is in early Peorian time. How long before the beginning of the Peor-

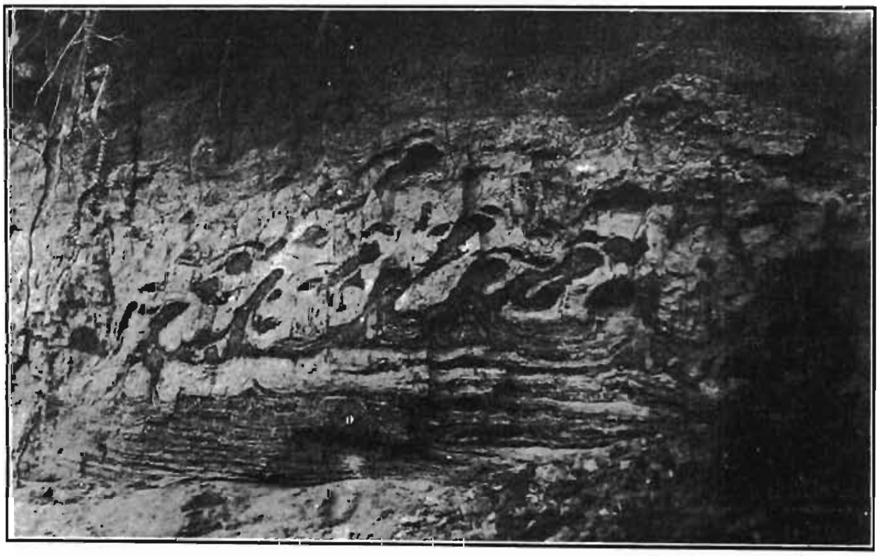


FIG. 58.—Contorted sand streaks and pockets in gray loess in the Butler pit in section 1, Union township, a mile south of Arion. The dark bands and patches in the middle of the picture are sand while the lighter parts are loess. Probably the contortions in the interbedded sand and loess are due to hillside slumping while the loess was being laid down. See W. J. Miller, Intraformational Corrugated Rocks: Jour. Geol., vol. XXX, p. 597; 1922.

ian the events occurred is, again, doubtful. The gravels are for the most part fresh and unleached of their lime content. In some instances they are interbanded with loess, as for instance in the Butler pit, shown in figure 58. In some cases they make distinct terraces or shoulders on the valley walls, in others their slopes seem to merge into those of the previous surface. At least the loess has concealed any topographic differences which may have originally existed. The first fact seems to point to a short interval between the release of the gravels from the till and the deposition of the loess. The second fact may point in the same direction although not necessarily so. The topographic features may indicate that after the gravels were carried into the valleys the whole topography was again so modified by erosion as to bring the slopes of valley and gravel into uniformity before the loess blanketed the surface.

There is another factor which should be considered. Originally, of course, the gravels must have extended from wall to wall of the valleys. Now they exist as mere remnants of their former mass. If the clearing out of the valleys took place before the loess was laid down it means a rather long interval between the formation of the two types of material. Some of the gravel de-

FIG. 59. Deep gully in loess in the north edge of the Boyer flood plain, in the southeast quarter of section 5, Union township. Looking north toward the upland.

posits have no loess over them, some have a few feet and some are heavily covered. It is usually difficult to determine whether the loess extends down the slopes of the gravel beds or not. One or two exposures in Boyer valley may be significant. In the southeast quarter of section 3, Union township, a deep gully extends from the north edge of the valley southward to the river, across a low bench. It is twenty feet deep and scarcely as wide at the top, and is cut down to the level of the flood plain. Through its entire depth and extent it shows only loess, which is yellow for the most part although in the lower foot or two it is brownish gray. Figure 59 gives a view of this gully. Again, the ditch cut for straightening the Boyer channel shows, at the bridge just north of Dow City and near the gully just described, beneath three feet of black humus and alluvium eight feet of yellow or brownish compact loesslike silt very similar to that found in the gully, and probably of the same origin and nature. These exposures are between the gravel pits below Arion and those above Dunlap. They seem to show that the valley had been fairly well cleared of gravel before the deposition of the loess took place.

Because of the fossil remains found in the sands of the Mill pit at Denison these were formerly considered to be of Aftonian age. But there is no drift over these sands, nor indeed over any of the similar deposits found in this and other counties. Furthermore, similar remains have been found in and upon glacial and interglacial deposits of much later age, as, for instance, in the loess of this same pit. Hence the presence of fossils in these sands and gravels has no bearing upon their age, and the fact that the deposits are nowhere overlain by drift renders an assignment of a pre-Kansan age very doubtful indeed. Besides we have reviewed evidence for considering them to be younger than Kansan.

The gravels here considered must be distinguished clearly from certain other deposits which have been assigned to the Aftonian but whose geologic relations are quite different from those of the gravels herein discussed. These so-called Aftonian gravels were considered to be of that age because they are usually overlain as well as underlain by till, and also because in many of them fossil remains of various mammals were found. We have already mentioned the value of the fossils as evidence and it may be said of the presence of till that there is nothing to prove that both underlying and overlying till are not of the same age. It was formerly thought that the underlying till was Nebraskan while the overlying was Kansan. But it is possible that the till is all of the same age and it may be either Kansan or Nebraskan. Hence the gravels probably are not horizon markers neither is it certain that they are interglacial in age, as are the gravels in which we are interested. Probably they represent masses of gravel which were carried out from beneath the ice by escaping waters and later were picked up by the advancing glacier. Such enclosed masses are very common in Monona county, as for example near Ute, Mapleton, Grant Center, Turin; and also in Harrison county, notably near Missouri Valley. They are present also in the counties to the north but have not been found to be so numerous in Crawford county.[37]

To summarize: the evidence indicates that these sands and gravels which are now spread over the hills and gathered in the valleys were released from the Kansan till—and locally from the Nebraskan—by rapid erosion made possible through differential uplift centering to the north of Crawford county. This erosion occurred long after the close of Kansan glaciation and probably a considerable period before the deposition of the loess. Later much of the material was carried farther down the valleys out of our region, but some still remains along the valley walls and elsewhere. There is no evidence to show that the deposits are older than Kansan time but they must be older than Wisconsin glaciation because they are covered by loess, which was deposited in Peorian time, between Iowan and Wisconsin glaciations.

Wisconsin Gravels.—Since the western margin of the Wisconsin glacier lay across the sag which opens into Boyer valley in southern Sac county probably there were some sands and gravels carried down this opening when the Wisconsin ice was melting. These gravels are very prominent around the west end of Wall lake and probably furnish the water for the city well at the town of Wall Lake. Here they are overlain by fifteen to twenty feet of black sandy material. It is possible, of course, that these sands and gravels in the valley bottom are partly Wisconsin and partly preloessial in age, and the same may be true of the gravels farther down, as at Denison, where the old city wells reach them. These wells are described under the heading of Water Supplies.

THE LOESS

It has been necessary to mention the loess frequently in preceding discussions but it may be best to describe it and its rela-

37 For further discussion of these gravels see the following papers: Kay, George F.; Twenty-eighth and Twenty-ninth Annual Reports of the Director: Iowa Geol. Survey, vol. XXIX, pp. xv-xviii. Lees, James H., Valley Gravels of Northwestern Iowa: Bull. Geol. Soc. America, vol. 32, pp. 49, 50.

tions here in some detail. In its present form loess is an eolian deposit, that is it is wind-blown material carried up from river flats and other areas of loose fine clays where scarcity of vegetation in the past permitted the winds to pick up and convey large quantities of dust, to be dropped when and where the force of the wind abated. The Missouri river bottoms afford the best field in western Iowa for these operations of the wind and consequently the lands bordering the great valley are piled high with this fine dustlike material known as loess. The hills and fields of Crawford county have shared in this blanketing and so are covered by an almost universal veneer of loess, except along the valleys. There is quite a noticeable difference in the general thickness of the loess in the eastern and western parts of the county, so that while in the eastern townships the drift may be found projecting through the loess in spots or is frequently reached in road gradings and similar cuttings, in the western townships it is but seldom that one will see drift, so thick is the loess covering. We have seen that in railway cuts in eastern Crawford thicknesses of twenty feet and more of loess have been penetrated and farther west the thickness will average even more than this.

It is a notable feature that the loess is usually thicker on hillsides than on the hilltops, showing that it has smoothed out a topography which before the loess covered it was more rugged than now, with steeper slopes and sharper profiles. In eastern Crawford the resulting surface has smoothly flowing contours and a fairly level skyline. Farther west, where the loess is thicker, it is piled on the hills in billowy masses, giving a wavy profile to the topography. Still farther west near the Missouri bluffs, the surface is extremely rugged and is characterized by sharp-edged ridges and exceedingly steep slopes.

Age of the Loess.—When the Kansan glacier melted away and left its sheet of glacial drift this drift doubtless had a fairly level surface. But the loess was laid on a surface of great irregularity, made so by the erosive action of rains and streams and all the forces which cut down the land and carry it away to lower levels. The formation of such a topography as that over which the loess was laid takes a great length of time. Indeed Yarmouth time, during which that topography was in the making, is estimated to have covered hundreds of thousands and perhaps several millions of years. Hence it is certain that the period of great loess formation followed that of Kansan glaciation by an exceedingly long interval. Again, as was suggested on page 334, the Yarmouth interglacial age was followed by two glacial ages —the Illinoian and the Iowan—and by an interglacial age—the Sangamon—between these two glacial ages before the loess was formed. We know this because in eastern Iowa the Iowan drift

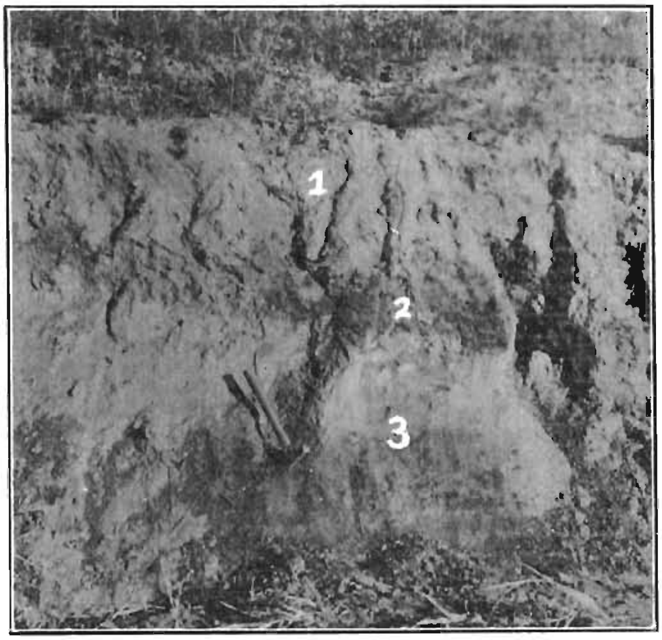


FIG. 60.—Yellow loess (1) over gray (3), with a réd band (2) between. The northeast quarter of section 26, Willow township.

is margined and, in places along its edge, overlapped by loess, which, while undoubtedly of local origin is probably of the same age as the loess of the Missouri slope. On the other hand we know that the loess is older than the Wisconsin drift because in some places loess has been found under that drift, while there is no loess on it. From all these facts it is quite certain that the loess was formed, at least the major part of it, during the period succeeding the Iowan invasion, that is during the Peorian interglacial age, and probably during the early part of that age, before vegetation had covered the sources of supply whence the loess dust was derived.

Character of the Loess.—The typical loess shows two phases, aside from the surface part, which has been modified somewhat by plant growth and decay and is usually brownish. In a thick bed there may often be seen an upper yellow part and a lower gray part, as for example the exposure shown in figure 60. In some cases there is a gradation or an interfingering from yellow to gray while in others the transition is abrupt. It does not

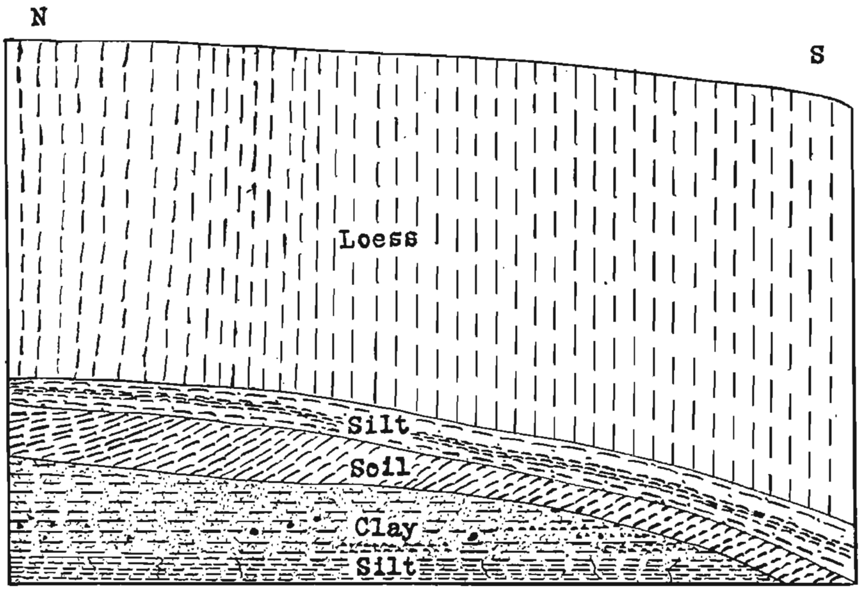


FIG. 61.—Diagrammatic section of the face of the Green and Ward clay pit, on the east edge of Denison.

seem likely that the two colors represent distinctions in age or origin. The upper parts of the loess are as a rule leached of their lime content, but the inferior parts of thick beds, whether yellow or gray, are usually quite calcareous. In many cases irregularly spherical balls of lime called loess kindchen are scattered throughout the loess. These are formed by secondary concentration of lime which has been leached from the parts above. In addition, in most places, there are in the calcareous parts numerous small snail shells, remains of the life forms which existed on the ground while the loess was being deposited. Since these snails were land forms they bear additional testimony to the eolian origin of the loess.

Relations of the Loess.—We have seen that the loess overlies indifferently Nebraskan till or gumbotil, Kansan till or gumbotil or the post-Kansan gravels. The contact with the tills and gumbotils is usually sharp and there is little difficulty in distinguishing the two classes of material. Where the loess is thin and

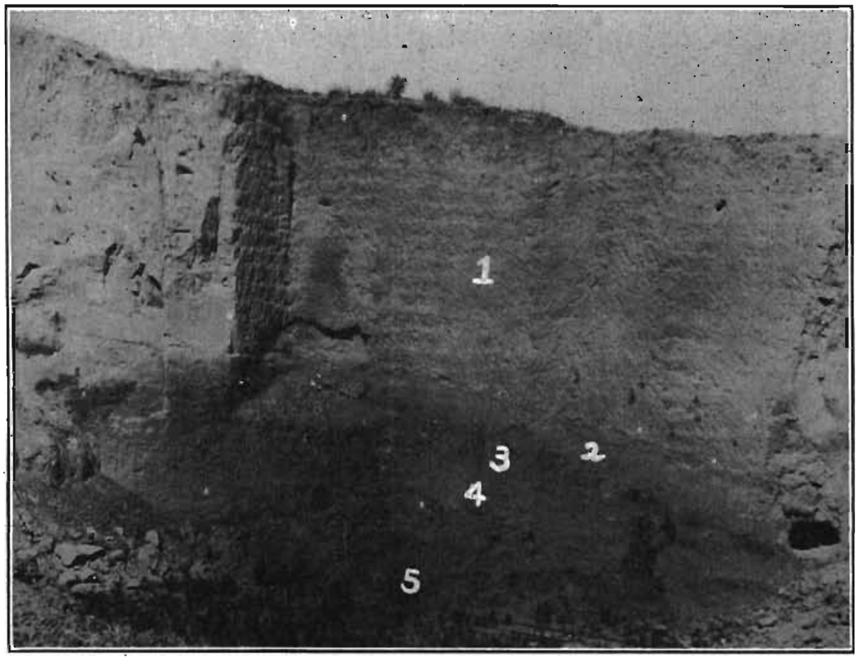


FIG. 62.—View of the face of the Green and Ward clay pit (Denison Brick Co.), Denison. 1, Loess; 2, silt, with small cave; 3, soil band; 4, sandy clay; 5, silt.

leached and modified in color as well as in texture it comes to resemble the modified gumbotil, which like this loess bears no pebbles and has no lime content, unless it should be in the form of small secondary lime balls. Where the loess overlies the gravels it is in some cases interleaved at the contact. Because the loess is so widely distributed over Crawford county it is the most important soil in the county and as such will be discussed at greater length under the heading of Soils.

It is not needful to give here detailed sections of the loess, as several have been presented in connection with other members of the Pleistocene. However, it is perhaps worth while to describe one section because of the rather unusual succession of strata and their mutual relations. This section is found, or rather was found, in the upper, old pit of the now abandoned Green and Ward brickyard in the eastern confines of Denison. The brickyard is on the slope of East Boyer valley which it overlooks from the north. The pit showed the following section, which is also shown diagramatically in figure 61 and photographically in figure 62:

		FEET
1.	Loess, yellow, upper ten feet leached, no fossils or lime concretions; lower part calcareous, abundant fossils, some concretions, finely laminated, gray near base. Rests unconformably on sloping surface of number 2, thickens to south	15 to 25
2.	Silt or fine clay, brownish in upper part, then nearly black for a foot, then brownish in lower part; very few small pebbles, the largest seen being a piece of feldspar an inch in diameter. This member slopes toward the river, of whose valley wall it evidently formed the upper member before the loess was laid above it. Thickens toward the valley	1 to 3
3.	Soil band (?), black; thickens as it rises to north; lies unconformably on eroded slope of number 4	1 to 3
4.	Clay, reddish yellow, finely sandy, streaks of gravel in lower part; cobbles up to three inches in diameter. Clay is hard above and is difficult to pick. Surface slopes toward valley and cuts off gravel layers. Maximum exposed thickness	6
5.	Silt, mixed gray and brown, finely siliceous, somewhat jointed	1 to 2

A newer pit 300 feet south of the old one and at the level of the floor of the old one exposes fifteen feet of bluish or brownish gray loess which is mottled gray-brown and yellow in its upper part. The lower members of the old pit were not reached in this one. A forty foot well between the pits went through the loess and into gravel. At the bottom is a tough dark blue clay, probably till. Since the level of these pits is below the general level of the Nebraskan gumbotil plain this till may be Nebraskan. The "gravel" may represent the sandy layers of the upper pit.

It seems probable that all the members of this section are post-Kansan. If so they show that after the till had been weathered and eroded a soil band was formed over the slopes and that later still the loess was deposited on the now mature topography. A ball and socket joint, probably of an elephant, was found in the soil band, and numerous teeth and bones have been taken from the loess.

ECONOMIC GEOLOGY

Soils

Crawford county is essentially an agricultural district. While there are some industrial plants within the county they are nearly all directly dependent upon the agricultural activities of the surrounding region, and it is highly probable that any further development in the industrial life of the community will be based largely upon the growth and improvement of agriculture.

The soils of the county are an invaluable storehouse and rightly used and cared for will continue to yield their stores abundantly for generations to come. But like all storehouses their supplies are not limitless. ''Mining the soil'' as we mine coal, continually drawing out the richness of the soil as our stores of coal are drawn from the heart of Mother Earth, without returning anything to replace what is withdrawn—this means certain exhaustion and ultimate ruin. While the danger may not be immediate it is none the less real, as the abandoned farms of New England and the fertilized soils of the eastern states bear witness. This simply means that precaution should be exercised against the wasting of the soil by stream and rain wash, that gullies must not be allowed to cut up the fields and pastures. It means that care must be used in proper rotation of crops, that, for example, if timothy has been cropped on a field clover should be sown, as clover is one of the most helpful crops to the soil while timothy drains a soil of its plant food more quickly, almost, than any other crop. This is not a dissertation on farm crops and this is not the place to discuss these matters at length. It is desired simply to point out and emphasize the necessity for the use of care and intelligence in relation to this the most vital of the problems of reasonable conservation of Crawford county's natural wealth.

The soils of the county are of two classes, the loess soils of the uplands and the alluvial soils of the larger stream valleys. Some of the steep hillsides are bare of loess and the drift clays or gravels immediately underlie the black top soil. Also the gravels of the valleys are in many places covered by only a thin veneer of soil or sod. But these constitute only a small percentage of the whole surface and the two first mentioned types are by far the most predominating.

Loess Soils.—On account of its peculiar characteristics the loess makes an admirable soil for many purposes. While it is a very fine-grained material it is at the same time quite porous. It has been determined that 80 per cent of the particles comprising the loess of western Iowa are smaller than grains of fine sand and yet have a diameter not smaller than one sixty-fourth of a millimeter, 0.006 inch.[38] This texture allows an easy and rapid passage of excess water and on the other hand facilitates by capillary action the drawing up of water from below to sustain growing crops in dry seasons. The loess soils as a rule have no true subsoils, as they cover the sheet of drift to such a depth that it has practically no influence on the character of the soil as used by the farmer. The seed bed, then, is merely the loess darkened by humus—the material resulting from growth and decay of vegetation. On steep hillslopes this humus is washed off as fast as it forms, enriching the lowlands at the expense of the uplands. The resulting yellow patches are often conspicuous features of the hillside fields, and are generally distinguished also by the poorer quality of the crops. It should be noted that while the loess is rich in plant food, potash, lime, magnesia, phosphoric and sulphuric acids, it is not until these have been rendered available by solution and a vegetable mould has been mingled with the minerals of the soil that this or any other soil really becomes fertile. Hence the need for vigilance in the prevention of the washing away of the black top soil and hence also the real wastefulness of cultivating the steep slopes where the loss is likely to exceed the reward.

The loess of the Missouri slope forms a splendid corn soil and in some areas, as around Missouri Valley and Council Bluffs, it is being employed increasingly for orchards and vineyards. The Bulletin of the Iowa Experiment Station already quoted calls attention to the additional fact that the porosity of the loess is likely to be a retarding feature as well as an advantage, on ac-

38 Principal Soil Areas of Iowa: Agr. Exp. Sta., Iowa State College, Bull. 82, p. 377.

count of its permitting the rapid decay and leaching of the vegetable content, with a consequent deficiency in humus. Hence the loess soil may be slightly more backward in the spring than are the drift soils of similar productiveness. The case is cited of Carroll county, the eastern part of which has soil of Wisconsin age, the western a loess soil like that of Crawford county. The corn of the drift soil is likely to be eight or ten days in advance of the corn of the loess.

In the face of this condition it remains true that the loess soil raises excellent crops of corn and oats and, especially in the southeastern part of the county, large quantities of potatoes. This is one of the most important potato yielding localities in the state.

Alluvial Soils.—The valley bottoms of the larger streams, notably the Boyer and East Boyer, are filled with alluvium and these make excellent farm lands. The alluvium consists of the wash from higher land, both up the valley and along its sides. Loess silt mingled perhaps with clay from the till, humus from the centuries of vegetable growth, sand washed down by the floods, all combine to make a soil of boundless fertility. Although these regions are subject to floods, these very agents are the means of perpetuating the richness of these soils.

Underlying the true alluvium along these streams are extensive beds of sand and gravel which afford certain drainage to the surface soil.

From the steeper slopes facing the valleys and from a few hilltops over the country the loess blanket has been blown or washed away. Here the pebbly till comes to the surface. Such steep slopes are used for pasture or are covered with timber and brush. Any attempt to cultivate them would be likely to result in worse than failure.

Water Supply

Wells.—In every part of the county an abundance of water is obtained from the various members of the Pleistocene system. There are comparatively few deep wells in the county. Much the larger number are less than fifty feet deep. The wells in and near the county which reach the rock have been mentioned under the head of Stratigraphy (see pages 294 to 302). The artesian well at Dunlap has a very strong flow and the King well in section 9 of Hays township derives an abundant supply from the sandstone in which it ends.

The towns of the county with the exception of Denison derive their municipal water supplies from large shallow wells which have been dug in the valley bottoms for the most part.

Denison.—The Denison water supply was formerly derived from two shallow wells sunk in the East Boyer bottoms. These wells are twenty-two feet in diameter and thirty-two feet deep. The upper six feet of this depth is black soil and below this is twenty-two feet of bowlder-bearing clay. Beneath this is gravel which was penetrated to a depth of four feet. These wells had a capacity of 160,000 gallons per day. In 1916 the city abandoned these wells and began using the water from the new deep well, which was completed March 10, 1916, by W. H. Gray and Brother of Chicago. The record of the strata and other information regarding this well are given on pages 297 to 301. On completion of the well the water stood eighty-eight feet below the surface and the pumping capacity was 200 gallons per minute. The level of the water was constant at a depth of 170 feet and its temperature was 66° F. There are about nineteen miles of mains and seventy hydrants and the water is used by about 750 families. The sanitary analysis is as follows, stated in parts per million:

Date collected, July 26, 1920
Odor-none; color—none; turbidity—none; sediment—trace
Ammonia nitrogen— 0.060
Albumenoid nitrogen—0.008
Nitrite nitrogen— 0.004
Nitrate nitrogen— 2.000
Chlorine— 66.000
Bacteria per c.c. at 37°C. on litmus lactose agar—7
At 20°C. on plain nutrient agar—90.
Acid colonies in 1 c.c. on litmus lactose agar—none.
Gas forming bacteria in lactose broth at 37°C.—none.
Quality—satisfactory.

Jack J. Hinman, Jr.,
Laboratories, State Board of Health, State University of Iowa.

Water from one of the shallow wells east of the present pumping plant was analyzed at Iowa State College in September, 1920, and the following report was made, stated in parts per million:

Total solids	623
Calcium	111
Magnesium	40
Sulphur (SO_4)	137
Chlorine	36

The analyst recommended using 19 ounces soda ash (Na_2SO_4) and 20 ounces lime (CaO) to 1000 gallons of water to precipitate the salts of calcium and magnesium which give the water its hardness and form scale in the boiler.

Partial analyses were made of water from two of the forty-foot wells north of the plant with the following results:

Calcium bicarbonate, 30 grains per gallon.
Magnesium sulphate, 32 grains per gallon.

Analysis of water from the river near by showed:

Calcium bicarbonate, 19 grains per gallon.
Magnesium bicarbonate, 51 grains per gallon.

These data were kindly furnished by the city officials of Denison.

The Chicago and North Western Railway Company has several water stations in Crawford county and of these the two at Denison and at West Side are of especial interest on account of the water softening plants operated in connection. The well at Denison is eighteen feet wide and twenty-five feet deep. As the water from this well contains a good deal of mineral matter which forms hard scale in boilers it is necessary to remove this before the water is used in locomotives. To accomplish this result a relatively simple apparatus is employed to mix with the water a prescribed amount of quick lime and soda ash. About seventy-five pounds of soda ash and ninety pounds of lime are used for treating 50,000 gallons of water. The lime combines with the carbonates of lime and magnesia dissolved in the water and precipitates these as white sludge. The soda ash likewise unites with the sulphates of lime (gypsum) and of magnesia which are present in the untreated water and they are thrown out of solution. In this way nearly all of the scale-forming minerals are removed from the water. Two gallon samples of the untreated water are sent to the company chemist each week. An analysis of the water is as follows, stated in grains per gallon:

	BEFORE TREATMENT	AFTER TREATMENT
Total solid matter	24.19	16.50
This solid matter consists of:		
Carbonate of lime	14.68	2.16
Carbonate of magnesia	2.51	2.05
Sulphate of lime	3.60	---- ----
Sulphate of magnesia	1.20	---- ----
Oxides of iron and aluminum	0.09	0.06
Silica	0.96	0.86
Incrusting solids	23.04	5.13
Alkali chlorides	1.15	2.38
Alkali sulphates	---- ----	7.77
Alkalı carbonates	---- ----	1.22
Non-incrusting solids	1.15	11.37
Pounds of scale-forming matter in 1,000 gallons	3.29	0.73

The water used at West Side is one of the hardest of the waters in use along the Iowa division of the Chicago and North Western railway. In amount of solid matter contained it is exceeded only by the water used at Council Bluffs, which carries 53.67 grains per gallon, or 6.69 pounds of scale-forming matter in 1,000 gallons. The result of the treatment of the West Side water may be seen from the following analyses, stated in grains per gallon.[39]

	BEFORE TREATMENT	AFTER TREATMENT
Total solid matter	51.33	28.18
This solid matter consists of:		
Carbonate of lime	17.32	2.67
Carbonate of magnesia	11.70	---- ----
Sulphate of lime	11.55	---- ----
Sulphate of magnesia	1.09	1.54
Oxides of iron and alumium	0.64	trace
Silica	1.55	0.54
Incrusting solids	43.85	4.75
Alkali chlorides	6.32	3.42
Alkali sulphate	1.16	20.01
Non-incrusting solids	7.48	23.43
Pounds of scale-forming matter in 1,000 gallons	6.26	0.68

The well from which the water is derived is thirty feet deep and twelve feet wide. The water comes within six feet of the

39 For the information regarding the treatment of the water at Denison and West Side the Survey is indebted to Mr. G. M. Davidson, chemist for the Chicago and North Western Railway Co., who is also the designer of the apparatus used at Denison. For description and illustrations of this apparatus and method see a paper by Mr. Davidson in Official Proceedings of the Western Railway Club, vol. 15, no. 6, February 17, 1903.

surface. The character of the strata is unknown, but the aquifer is doubtless sand or gravel.

The Nicholson Produce Company of Denison gets the water for its refrigerating plant from a thirty-five foot well twenty feet wide cased with a sixteen inch brick wall. This well was opened in March, 1909, and is sunk through eight feet of black soil, then through blue clay underlain by a thin layer of yellow loam in which was found wood cut by beavers. Beneath the loam is yellow clay, then gravel at the bottom. The air in the well has a fetid odor as if from vegetation, doubtless in one of the water-bearing layers. The well is stated to have a pumping capacity of seventy-five gallons per minute. Mr. Nicholson kindly furnished the writer with the following analysis and notes, made by the Dearborn Drug and Chemical Works, Chicago, August 4, 1910.

	GR. PER GAL.
Silica	.817
Oxides of iron and aluminum	.082
Carbonate of lime	11.481
Nitrate of lime	1.214
Sulphate of lime	8.112
Carbonate of magnesia	6.229
Sodium and potassium sulphates	trace
” ” ” chlorides	2.720
” ” ” nitrates	2.786
Loss &c.	.081
Total mineral solids	33.522
Organic matter	trace
Total incrusting solids	27.935
Total non-incrusting solids	5.587
Pounds incrusting solids per 1,000 U. S. gallons	3.98
Pounds non-incrusting solids per 1,000 U. S. gallons	0.80

"This water will cause the formation of more than twice an average amount of incrustation which will be decidedly hard, impervious, persistent and tenacious. There will also be a tendency to its causing trouble under certain conditions in the way of corrosion and pitting, due to the character of the sodium and potassium salts present and the nitrate of lime."

The water is run through a Stillwell heater to remove hardness.

*West Side.**—The town of West Side is supplied from a well located in the East Boyer bottoms. This well passes through fourteen or fifteen feet of alluvium, one or two feet of yellow

* The water supply data have been recently revised from the bulletins of the Iowa Insurance Service Bureau of Des Moines, which were kindly loaned by Mr. K. L. Walling, the manager.

sandy clay and eight feet of very fine sand, which is almost quicksand. The well will allow the pumping of 20,000 gallons per day and in addition five feet of water is left in the well to avoid drawing out the sand. A pump with capacity of 130,000 gallons per day is used and the water is pumped into a tank with a capacity of 40,000 gallons. The well is bricked up to the surface. Analyses are made twice a year. Consumption is about 30,000 gallons per day. The railway well is described on page 349.

Vail.—Vail gets its water supply from eight two inch sand point wells ranging in depth from eighteen to twenty-two feet. Sand and gravel in the river valley form the aquifer. The pumps used have a capacity of 120 gallons per minute and have never exhausted the wells. There are also two wells twenty-five feet deep and twelve feet in diameter which are pumped by a windmill. These are on the hillside but also penetrate the gravel.

Schleswig.—Schleswig installed a water system in the autumn of 1910. The wells are located in one of the broad shallow sags draining into Beaver creek and are probably one-fourth mile or more beyond the outskirts of the town and seventy-five to one hundred feet below the hilltops. The two original wells were ten and twelve feet in diameter and twenty-five feet deep, were sunk entirely in sand and gravel and were brick lined and covered with wood roofs. They proved inadequate and so ten shallow wells lined with 12 inch tile were installed in 1921. They are connected with each other and with the old wells by an intake pipe and any one can be shut off. The pump has a capacity of 250,000 gallons per day and is worked by a 15 horse power motor. The tank has a capacity of 60,000 gallons. Consumption is about 30,000 gallons daily.

Ricketts.—The village of Ricketts has a water system supplied by six 2½ inch sand points sunk nineteen feet below the bottom of a ten foot well. The points penetrate a sand bed for seven feet. They are sunk in the valley of Middle Soldier river on the south edge of town. The pump has capacity of 50,000 gallons per day. About 8,000 gallons per day is used.

Charter Oak.—The Charter Oak well is on the bottom lands of East Soldier river and is forty-five feet deep and twenty-nine feet wide. It ends in a bed of sand and gravel. A concrete standpipe having a capacity of 80,000 gallons stands 150 feet above the business district.

Arion.—Arion is supplied with water from a six inch well on the edge of the Boyer flats. It is fifty-six feet deep and penetrates a yellow pebbly clay overlying an abundantly water-bearing gravel bed. A thin layer of quicksand separates the two layers. A six horse-power oil engine is used to operate the deep well pump, which has a daily capacity of 40,000 gallons. A 23,000 gallon cistern on the top of the bluff, 155 feet above the well curb, is used for storage and gives a pressure in the town of seventy pounds. The water is very pure, does not scale in boilers and is in general use throughout the village, for both fire protection and domestic purposes.

Manilla.—The public water supply for Manilla is gained from two six-inch wells sixty-four and sixty-eight feet deep, situated in a ravine back from the river valley. Water is pumped by the municipal electric light plant. There are about two miles of mains and 150 users consume 60,000 gallons daily. The well at the electric light plant on the bottoms goes through four feet of black loam, ten feet of yellow clay and nine feet of coarse sand. It yields 10,000 gallons a day.

Mr. H. P. Achey, water supply foreman for the Chicago, Milwaukee and St. Paul Railway at Manilla, has kindly furnished the following information regarding the wells which supply the railway at that town. There are five drilled wells all of which are ten inches in diameter. All are located close to the pumping station.

Well No. 1, no log, tested 115 gallons per minute for three days.

Well No. 2

	DEPTH FEET
Yellow clay	0–25
Blue clay	25–30
Fine sand	30–40
Coarse sand	40–44
Coarse gravel	44–49
Clay	49–49.5

Test, 50 gallons per minute.

Well No. 4

	DEPTH FEET
Yellow clay	0–25
Blue clay	25–30
Sewer mud and fine sand	30–38
Coarse gravel	38–47.5
Clay	47.5–48

Test, 120 gallons per minute for ten days.

The logs of Nos. 3 and 5 are similar to those given.

The well at the old La Turno brickyard in the western part of Manilla, perhaps fifty feet above the bottom lands, was forty-five feet deep and penetrated loess and blue clay to gravel. The house well near by and probably twenty-five feet higher is thirty-six feet deep and is entirely in loess.

Mr. E. H. Woodard drilled a well in Manilla to a depth of 305 feet. Below eleven feet of black soil the entire depth was in blue clay. Four miles north of Manilla in section 2, Nishnabotany township, is the Clayton Baker well, 515 feet deep. The following is the driller's log: Yellow clay, loess in upper 50 feet, 75 feet; sand (water), 2 feet; blue clay and pebbles, 408 feet; "hardpan," 20; sand and gravel (water), 10. This is one of the deepest drift wells in the state. It is situated on a high ridge and shows well the great depth of the Pleistocene deposits in this part of the state.

Country wells.—In the vicinity of Vail country wells are generally from fifteen to forty-five feet deep. They go through a yellow clay into gravel but if a blue clay is struck instead of the gravel there is no water for 120 feet or so, where a lower gravel is reached. If the wells penetrate the gravel under the upper yellow clay they strike another yellow limy pebbly clay. It would seem as if the upper clay is loess, the gravel post-Kansan and the blue clay Kansan drift. The deep-lying gravel may be Aftonian. As an example of these shallow wells one in the northeast quarter of section 10, East Boyer township, may be mentioned. It is twenty-six feet deep and ends in sand. This one is located in a valley but is typical of many shallow wells of the county. Water is pumped into a cistern near the farm buildings, whence it is drawn for use.

Several deep wells in the eastern part of the county have been mentioned on page 294 and may be described in more detail here. The Peter Lorensen well, in section 10, Jackson township, is 500 feet deep. It passes through loess for twenty feet; then through blue and yellow clay with five sandy layers each two to three feet thick, but with no water, for 200 feet; blue clay for 200 feet; quicksand, very fine, for 100 feet.

In the south half of section 27, same township, is the well of McCaffery Brothers, 662 feet deep. The succession of strata is similar in the upper part to that in the Lorensen well, including: loess, twenty feet; blue and yellow clay, 100 feet; blue clay, 180 feet. Below this is a yellow limestone, so hard that the hydraulic churn drill could penetrate it only one and one-half to two feet per day. In spite of this the well is reported to have penetrated the limestone for 357 feet.

The Jonathan Miller well, located in the east half of the southwest quarter of section 16, Milford township, reaches a depth of 492 feet and passes through twenty feet of loess, fifty-five feet of very bowldery till, and then blue clay, bowldery, to rock at 460 feet. This rock is a blue-gray limestone and was penetrated for thirty feet.

A similar succession of Pleistocene deposits was encountered in the Franklin well in the northeast quarter of section 17, East Boyer. This well is located on a hilltop, is 404 feet deep and struck a very coarse sandstone at 390 feet.

The Barnhoff or King well, section 9, Hayes, is similar to the others except for one feature. Fifteen or twenty feet of loess overlies eighty feet of yellow and blue pebbly clay. Then follows 100 feet of blue clay, succeeded by what Mr. Hoffard, the driller, terms "potter's clay," a light blue-gray clay which contains some pebbles and which does not check on drying. It extends to the depth of 550 feet where a gray rather coarse sandstone is entered. This is penetrated for twenty-two and one-half feet and furnishes a strong flow of water. The well is drilled from a hilltop and if the "potter's clay" is all Pleistocene till this well must be the deepest drift well in the region and perhaps in the state.

In the southeastern part of the county the wells are usually sunk in low ground and the water is forced into cisterns to supply the barns and houses. In many instances the cisterns are located on hillsides above the buildings, and distribution is effected by gravity systems. This plan of pumping the water into cisterns and piping it about the homestead is a very common one all over the county and is the means used by about half of the farmers for insuring a supply of water. Not all the wells are in low ground, although even on higher land they are quite shallow, ranging in depth from fifteen to twenty-five, or more rarely to thirty-five feet. They generally pass through yellow clay, in some cases, at least, loess, and enter a layer of gravel and sand. This bed does not seem to be very thick, in some wells not over two feet, but the supply is said to be abundant, even in dry seasons. Some wells are reported to have been dug to a depth of eighty feet without finding water, presumably because of the absence of the gravel bed. One well in the southwest quarter of section 1, Iowa, is twenty-five feet deep, and one in the southwest quarter of section 36, Hays, is fifteen feet deep. Both pass through yellow pebbly (?) clay, perhaps loess bearing kindchen, and reach gravel. Two wells on the upland in the southwest quarter of section 13 and another across the road in the southeast quarter of section 14, Nishnabotany, are thirty-two feet deep and pass through loess to gravel. The water in all these wells is said to be of excellent quality.

Wells in western Crawford are similar to those described above. One on a farm in the southwest quarter of section 23, Hanover, is fifteen feet deep and draws an abundant supply, even in times of such severe testing as the summer of 1910, from a gravel layer underlying a gray pebbleless clay, doubtless loess. Water is forced up into a cistern near the house. Most wells in this vicinity are twenty to twenty-five feet deep.

It seems most reasonable to assume that the aquifer of these shallow wells is the post-Kansan gravel. The water-bearing stratum immediately underlies the loess and therefore there is no basis for placing it any farther down in the geological column than the Yarmouth. The blue or blue and yellow clay which has been found under the gravel in some cases may well be the Kansan as its characters agree better with the known features of this till than with those of the older Nebraskan, although some of the deeper wells doubtless have reached this lower till.

Mr. Henry Rickert of Schleswig, in company with Mr. Henry Hansen, has dug several wells near Schleswig. Mr. Rickert has kindly furnished the following information. The Henry Naeve well, in the northeast quarter of section 19, Otter Creek township, is 390 feet deep. It passed through loess and yellow and blue till to 118 feet where the first water was reached in a seven or eight foot layer of sand and gravel. This was overlain by blue clay and below it also is blue clay to the bottom of the well.

The well on the farm of Mrs. Mary Herring, across the road from Mr. Naeve, in the southeast quarter of section 18, is 410 feet deep. The strata passed through here were the same as those in the Naeve well and in addition the lower twenty feet, from 390 to 410 feet is in "soapstone." Whether this represents the Benton or the Des Moines shale or is a hard layer of Nebraskan or other till is not clear. Both of these wells are on high ground, more than 1,500 feet above sea level.

The Fred Shurkey well, northwest quarter section 12, Otter Creek, is 373 feet deep and pierces the same succession of loess, yellow and blue clay, with a sand layer at 120 feet. There was not much water in the sand as here penetrated.

Along the Boyer the gravels supply an abundance of water. The hill on which Deloit is built is veneered with gravel and nearly all the wells on the hill as well as those in the valley draw their waters from this source. It underlies also the alluvium of the river plain.

Mr. W. A. Davie has drilled several wells in southwestern Crawford and the following records were furnished by him. They are typical of conditions in this area. Mrs. Talcott owns a well in section 12, Union township, which is sunk to the depth of 234 feet, fifty feet of which was in loess, 175 feet in yellow drift, a few feet in blue clay, and the last ten feet in a rather fine sand. There is a "soapstone," so-called, at the base of the yellow clay. It is light-colored, bears lime balls and is in many cases very hard although it is softer as it is found at greater depth. The "soapstone," however, seems to belong to the glacial series, on account of its relations to the other members of the Pleistocene.

In section 5 of Union township Mr. S. J. Woodruff has a well which is 260 feet deep and which penetrates formations similar to those of the Talcott well. The same is true of the well of George Kern in section 31, Union. This is 315 feet deep and encountered the same blue clay above gravel.

Mr. Davie's well at his home on the southwest corner of section 36, Boyer, is 180 feet deep and the strata passed through include: loess, sixty feet; yellow clay, 100 feet; gravel, twenty-four feet. At the bottom is a blue-black clay, probably Nebraskan. The influence of the Missouri loess is plainly evident in all of these wells. The altitudes of these wells are probably not quite so great as are those of the deep wells described heretofore, as those were in the northern part of the county, which is naturally higher than more southern locations, and in addition the wells of the southern area are near the river valley and not quite on the uplands.

Springs.—Many of the minor streams are fed by seepage springs, some of which issue from the till, while others are fed from the gravels. Where these springs are conveniently located they are used for domestic purposes. Thus a small spring in the valley wall in the southeast part of section 26, Goodrich township, supplies the nearby farmhouse with a three-quarter inch stream. Probably it is fed from the gravels which are seen close by. In the southwest quarter of section 2, East Boyer, is another spring which supplies the farmhouse situated near. In the northwest quarter of section 24, Denison, is a large spring which forms the source for a brook two feet wide and eight inches deep.

Streams.—Crawford county is so thoroughly covered by a ramifying network of streams, large and small, that there is no lack of surface water in every township. The larger streams and indeed many of the smaller ones, such as Beaman creek, Paradise creek, Friends creek and numerous others, are perennial and furnish a never failing supply for farm use, unless we except such seasons of severe drought as those of 1910 and 1911.

Rainfall.—Since the determining factor in water supply is rainfall it may not be amiss to include here some statistics with regard to this subject. In order to make these data more general and cover a larger period of time than would be possible otherwise, figures from several stations in counties surrounding Crawford are included. The data are summarized from the published records of the Iowa Section of the United States Weather Bureau.

Precipitation at various stations

Date	Logan	Sac City	Grant City	Onawa	Denison	Carroll	Council Bluffs
1866	13.00[1]						
1867	27.81						
1868	29.85[2]						
1869	44.95		38.95[19]				
1870	25.30[3]		24.05[20]				
1871	28.95[4]		27.53[21]				28.49[30]
1872	32.10		---- ----				32.64
1873	43.20		---- ----				27.78
1874	28.40		---- ----				25.48
1875	42.00		---- ----				38.65
1876	28.20	29.98[10]	40.22				35.05
1877	45.10	30.07	29.10				38.72
1878	46.31[5]	30.00	31.06				34.69
1879	33.10	21.69	20.41	23.33			25.16
1880	27.30	22.83	23.27	23.42			---- ----
1881	56.60	46.55	29.48[22]	49.93			41.42[31]
1882	37.30	25.82	21.03[23]	31.34			30.23[32]
1883	39.90	---- ----	27.14	33.68			45.47
1884	36.60	42.54	---- ----	37.56			46.60
1885	40.20[6]	36.51	33.99	43.21			35.32
1886	23.10[7]	21.68	---- ----	33.01			27.85
1887	23.60	28.55	29.05	27.30			23.35
1888	34.02	30.33	---- ----	37.18			
			Sioux City				
1889	29.87	28.17	9.45[24]	27.42			
1890	34.95[8]	23.53	22.25	35.37		30.34	Omaha
1891	35.39	28.90	33.29	36.61		41.63	34.92
1892	35.25	24.78	26.38	25.76		24.82	29.44
1893	22.40	18.96[11]	23.05	27.27	24.53[25]	29.63	---- ----
1894	16.63	29.81	17.84	16.01	---- ----	20.42	17.82
1895	26.12	31.59	20.29	31.97	18.54[26]	23.32[29]	21.69
1896	43.82	38.92	30.77	42.17	36.40	41.83	35.90
1897	26.00	22.67	20.38	24.37	25.50	28.80	21.30
1898	24.96	27.54	22.91	31.35	---- ----	28.65	27.84
1899	31.95	---- ----	22.67	20.59	26.25	34.90	26.74
1900	31.39	34.21	32.22	42.20	33.90	40.18	31.20
1901	30.56	24.35	26.59	30.07	23.40	29.55	25.08
1902	40.74	42.77	20.34	42.25	33.81	43.94	30.48
1903	30.25	36.24	41.10	50.53	34.55	34.48	33.43
1904	24.14	25.48[12]	21.46	31.30	21.28	26.83	25.48
1905	30.35	31.93[13]	31.66	32.33	25.87	31.56	29.88
1906	38.05	23.49[14]	31.41	40.59	25.44[27]	22.79	27.59
1907	22.73	28.92[15]	19.93	21.55	28.48	29.24	24.60
1908	28.12	---- ----	26.44	31.33	37.24	42.52	27.10
1909	43.39	28.50[16]	---- ----	29.64	37.73	41.62	44.92
1910	19.03	14.75	---- ----	16.85	21.78	23.10	22.21
1911	23.12	33.92	24.02	24.81	22.79	24.18	18.46
1912	29.46	30.33	30.54	32.37	30.68	30.45	26.46
1913	31.59	27.39	30.31	30.32	28.32	29.93	25.03
1914	25.26	30.13	24.77	26.90	30.33	30.92	27.25
1915	38.27	41.27	33.46	46.01	38.05	41.19	31.57
1916	21.66[9]	19.66[17]	24.51	28.37	26.30	26.17	19.46
1917	25.43	18.66[18]	21.32	34.41	---- ----	27.66	22.62
1918	25.84	---- ----	25.41	---- ----	25.17[28]	31.31	21.44
1919	29.19	34.64	29.16	32.31	---- ----	32.48	29.70
1920	30.55	28.48	31.96	---- ----	27.64	33.47	23.01
1921	31.11	23.24	21.61	---- ----	32.57	37.63	25.29
1922	30.80	---- ----	25.94	---- ----	25.26	29.79	22.46
1923	36.65	29.37	34.50	36.09	29.98	33.13	30.95
1924	---- ----	24.92	22.82	31.86	28.45	32.30	26.83
1925	21.42	21.75	18.01	26.99	26.04	24.29	21.12
1926		30.59	24.26		30.75	36.79	25.96

Notes: 1, includes May-Sept.; 2, except Jan., Aug., Oct.; 3, except Feb., Nov.; 4, except Mar.; 5, except Nov.; 6, except Jan.; 7, except Sept.; 8, except Dec.; 9, except Mar.; 10, except Apr., and May; 11, except Sept.-Nov.; 12, except Dec.; 13, except Mar., Nov.; 14, except Dec.; 15, except Jan., Nov., Dec.; 16, except Jan.-Mar.; 17, except Oct.; 18, except Jan.; 19, except Jan. Feb.; 20, except Feb., Mar., Apr.; 21, except Sept.; 22, except Feb., Mar., Oct.; 23, except Mar., Nov.; 24, includes July-Dec.; 25, except Sept., Nov.; 26, except Jan.-Mar.; 27, except Dec.; 28, except Jan.; 29, except Jan.; 30, except Jan., Feb.; 31, except Feb., Mar.; 32, except Oct., Dec.

Average precipitation for Iowa.

1890	31.30	1903	35.39	1916	28.90
1891	32.90	1904	28.51	1917	27.81
1892	36.58	1905	36.56	1918	32.78
1893	27.59	1906	31.60	1919	36.76
1894	21.94	1907	31.61	1920	31.75
1895	26.77	1908	35.26	1921	32.03
1896	37.23	1909	40.01	1922	29.98
1897	26.98	1910	19.87	1923	29.50
1898	31.34	1911	31.37	1924	31.39
1899	28.68	1912	28.89	1925	28.24
1900	35.05	1913	29.95	1926	32.22
1901	24.41	1914	31.93		
1902	43.82	1915	39.53		

Normal precipitation, 31.97 inches.

Sand and Gravel

Sand and gravel are very generally distributed over the county as will have been seen from the descriptions of the gravels and of the wells. Where the overburden is deep sand and gravel are, to be sure, not available for pit work but in a great number of places their presence has been revealed by erosion. This is especially true of the Boyer valley, whose walls and floor are in many localities lined with deposits of sand and gravel. Some of these beds have been opened for commercial use but there are numerous deposits which can and doubtless will be put to use in the future. The most important exposures are indicated on the map which accompanies this report. As these have been discussed under the description of the Pleistocene it will be sufficient here to make brief mention of a few of the observed beds.

The erosive work of Porter and Wheeler creeks above Boyer has uncovered beds of sand at several points along their courses, and the same is true of Beaman and Trinkle creeks. The veneering of the Boyer wall at Deloit by gravel has been mentioned, and the McAhren pit, about one-half mile below the village, at the mouth of Otter creek, has supplied both sand and gravel of fine quality. The valleys of Otter and Buffalo creeks show many gravel beds, as for instance in sections 12, 34, 27, 15, 10 of Goodrich and 36 of Otter Creek townships.

At Denison the Mill sand pit, northwest corner section 14, Denison, and the Mill gravel bank one-half mile farther down the valley and in its floor, are well known for their fossil content as well as for the quality of their economic products. A smaller pit was opened some years ago by Mr. Will Quade near the Illinois Central station on Court street in Denison. Most of the layers here exposed are sand but some gravel bands occur also.

Where Buck creek debouches into the main valley the Chicago, Milwaukee and Saint Paul Railway Company has cut into a bed of fine sand which has, however, a rather heavy overburden of loess. This loess must thin out at the point of the ridge and here the sand should be nearer the surface. There are without doubt large quantities here, and one mile and two miles up Buck creek other masses are shown. At the latter point, southwest quarter of section 8, Washington, the ferruginous sands have been dug for various purposes. They should make excellent road metal.

A number of openings have been made below Arion. A small pit has been opened by Mr. Milo Kelly in the southwest quarter of section 1, Union, on the south side of the valley. It contains only fine sand with few pebbles. About one-half mile down the valley and on the same side, is the Charles Butler pit. This shows a face of thirty feet of sand and gravel, with a ten foot layer of loess above it. This top layer probably will be thicker as the pit face advances into the bluff. Near this pit is the exposure of sand and loess which shows interbanding of the two materials and a curious contortion of the sand pockets and bands. (See figure 58, page 335.) Other pits have been opened immediately below this one thus showing a practically continuous deposit for more than a mile down the valley. Across the valley at the mouth of Paradise creek is the Riddell pit. This is claimed by some users to yield the best gravel to be found in this vicinity. It is not so thick as some others but the contents are clean and the stripping is not so great nor does it thicken so abruptly as is the case where pits are opened in steep slopes. (See figure 57, page 330.)

The western part of the county is so deeply covered with loess that little else is exposed. Only rarely are the underlying beds revealed in the deeper gullies and other cuts. One of the few exposures of gravel is in a valley just south of the road on the north line of section 9, Soldier. Six feet or more is exposed, bearing all the marks of an old deposit, rusty rotten bowlders and yellow stains. Again on the south line of section 29, this township, is exposed eight feet of very rusty red gravel of medium fine size with numerous small bowlders and cobblestones.

Some exposures of sand are found along the East Boyer, as for instance along the road in sections 23 and 10, East Boyer township. These are very fine, are stained yellow and lie at the edge of the flood plain, where they are quite easy of access.

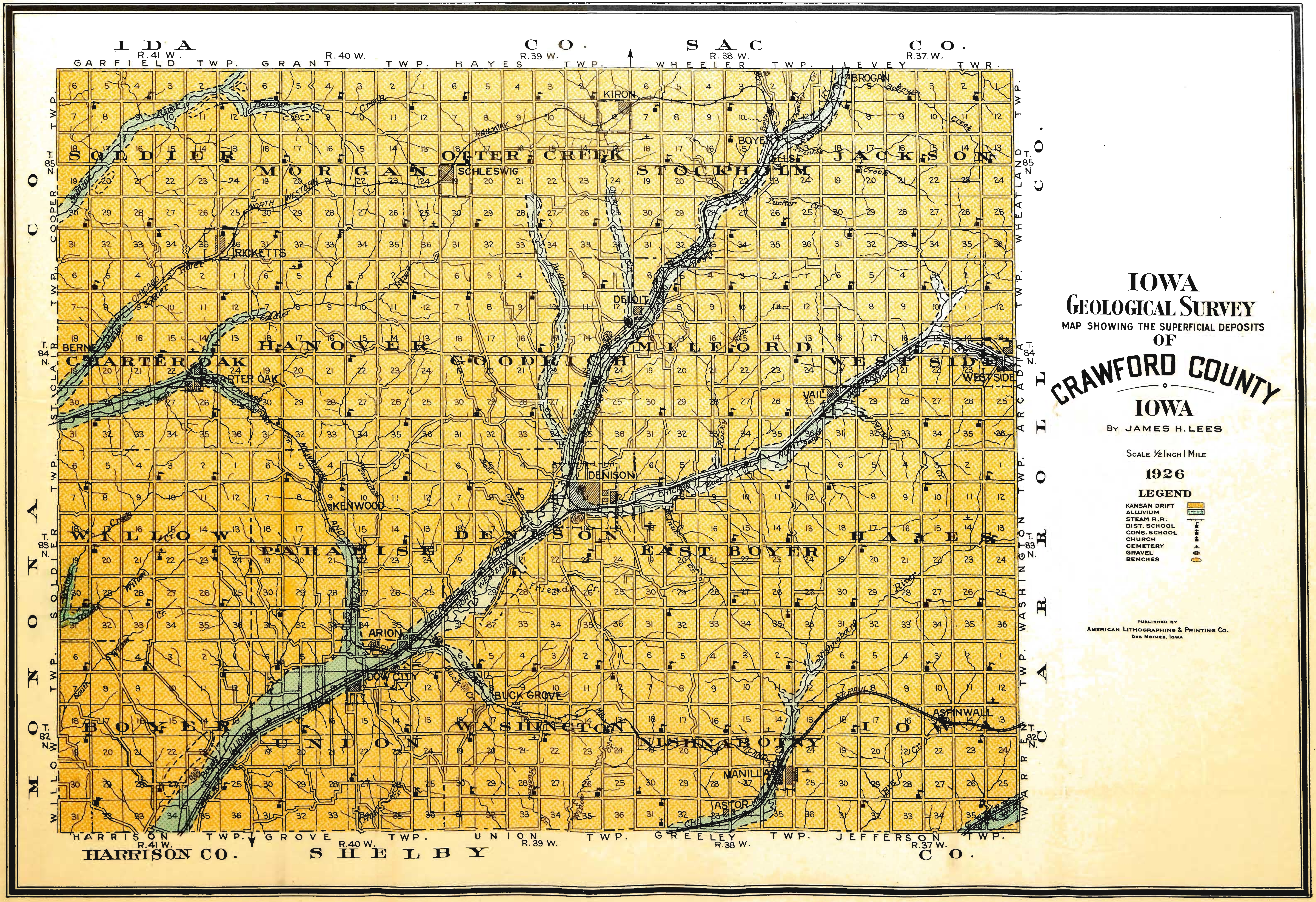
In the railroad cut in the center of section 14, Washington, a thickness of sixteen feet of red, oxidized gravels is exposed. This is near the headwaters of Buck creek and it should certainly be no difficult matter to secure an abundance of this excellent material for use on roads and for other purposes to which it is adapted.

Brick Plants

Two plants producing common brick and similar materials have been operated in the county. Both of these used the loess. One of these was located at Denison and was operated by Messrs. A. C. Green and Son and J. Ward for over twenty years previous to 1910. The other was located at Manilla and was owned by Mr. J. L. La Turno for about ten years. It was abandoned in 1913. At present no plants are in operation.

Coal

Every community is anxious to secure a supply of fuel in its own vicinity and therefore it is not surprising that the citizens of Crawford county should have attempted to find coal in their county. Mr. A. C. Green, who was at that time a county supervisor, informs the writer that in 1875 a hole was bored on the land of Mr. J. H. Maloney, one mile east of Denison, in search of coal, on the recommendation of "Professor" Fox. The work was done under the authority of the Board of Supervisors and the county authorities, among whom was Mr. Maloney as Auditor. Mr. Green directed the work as representative of the county officials although he was not in favor of its being under-taken. In the lower part of the drilling small bits of coal were found but these apparently were from the drift. The hole was sunk to the depth of about 350 feet but no bed of coal was reached. Evidently the drill did not get down to the Coal Measures. Whether any coal would have been found had these been penetrated is a question. It should be noted that the samples of the deep well at Denison showed a few very small fragments of coal at a depth of 360 feet. How much coal there may be at this level, and what its quality, are questions which can not be answered without a large expenditure of time and money in careful prospecting and examinations. Crawford county lies west of the area in which coal is known with certainty to be present in the beds of the Des Moines series. The presence of coal seams in the Coal Measures of western Iowa has always been a matter of doubt and the thickness of the drift and the presence, over much of the area at least, of the overlying Cretaceous, renders the solution of the problem far from easy. It has seemed probable to some of the investigators in this part of Iowa that conditions here were not favorable to the formation of beds of plant remains such as those which now form our coal supplies in eastern and southern Iowa.


IOWA
GEOLOGICAL SURVEY
MAP SHOWING THE SUPERFICIAL DEPOSITS
OF
CRAWFORD COUNTY
IOWA
BY JAMES H. LEES
SCALE ½ INCH 1 MILE
1926
LEGEND
KANSAN DRIFT
ALLUVIUM
STEAM R.R.
DIST. SCHOOL
CONS. SCHOOL
CHURCH
CEMETERY
GRAVEL
BENCHES
PUBLISHED BY
AMERICAN LITHOGRAPHING & PRINTING CO.
DES MOINES, IOWA
IDA CO.
SAC CO.
MONONA CO.
CARROLL CO.
HARRISON CO.
SHELBY CO.
R.41 W.
R.40 W.
R.39 W.
R.38 W.
R.37 W.
T. 85 N.
T. 84 N.
T. 83 N.
T. 82 N.
SOLDIER
MORGAN
OTTER CREEK
STOCKHOLM
JACKSON
CHARTER OAK
HANOVER
GOODRICH
MILFORD
WEST SIDE
WILLOW
PARADISE
DENISON
EAST BOYER
HAYES
BOYER
UNION
WASHINGTON
NISHNABOTNY
IOWA
KIRON
SCHLESWIG
RICKETTS
BOYER
DELOIT
BERNE
VAIL
DENISON
KENWOOD
ARION
DOW CITY
BUCK GROVE
MANILLA
ASTOR
ASPINWALL
BROGAN