THE PLEISTOCENE GRAVELS OF IOWA

by

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INTRODUCTION

The State of Iowa is located near the middle of the North American continent. It is in the upper Mississippi Valley, its east boundary being the Mississippi river, its west boundary the Missouri river. Iowa's greatest length, east and west, is about 335 miles, its width 208 miles. Fenneman [1] includes this state within the Central Lowland physiographic province.

Although considerable information about the Pleistocene gravels of Iowa is available in published reports, chiefly in the many county reports of the Iowa Geological Survey, it has been recognized for some time that a comprehensive report on the gravels of the state, based upon extensive field and laboratory studies, would be of distinct value not only to the citizens of Iowa but to all persons interested in the scientific and economic aspects of gravels of glacial and of interglacial ages. This paper has been prepared to meet this need.

The distributions, characteristics, relationships, origins, and ages of the gravels of the state have been determined in the light of our most recent investigations and interpretations of the Pleistocene deposits of Iowa, the area in which the records of the Pleistocene glacial and interglacial ages have been preserved more satisfactorily for study than in any other known area.

During the past twenty-five years the senior author has been interested in the study of the glacial deposits of the state in all their aspects. The junior author has assisted in the field studies and has had charge of investigations in the sedimentation laboratory. In the field, hundreds of exposures of gravel and associated materials were studied in detail, and from many of these exposures samples were collected and studied later in the laboratory.

1 Fenneman, Nevin M., Physiography of Western United States, McGraw Hill Book Co., Plate I, 1931.

THE CLASSIFICATION AND SIGNIFICANT FEATURES OF THE PLEISTOCENE DEPOSITS OF IOWA

Kay's Recent Classification of the Pleistocene

A fairly comprehensive history, accompanied by references, of the investigations and classifications of the Pleistocene deposits of Iowa up to the year 1929 is available.[2] Since then the senior author [2a] has proposed some distinct revisions of previous classifications. His most recent classification for Iowa is as follows:

Period (System)	Epoch (Series)	Age (Stage)	Substage
		Recent	
	Eldoran		Mankato
Pleistocene		Wisconsin	Peorian
or			Iowan
	Centralian	Sangamon	
Glacial		Illinoian	
	Ottumwan	Yarmouth	
		Kansan	
	Grandian	Aftonian	
		Nebraskan	

In this classification the Pleistocene is given the rank of period (system), and the period (system) is divided into four epochs (series), each of which is further subdivided into ages (stages). In figure 1 an attempt has been made by means of diagrammatic sections of glacial and interglacial materials to represent the present-day interpretations of the relationships of the Pleistocene materials of the different stages in Iowa.

Nebraskan Drift and Related Materials

The oldest of the epochs (series), the Grandian, began with the advance of the Nebraskan ice sheet and ended with the oncoming of the Kansan ice sheet. It includes the Nebraskan glacial age (stage) and the Aftonian interglacial age (stage).

In Iowa and border districts, the first ice sheet, the Nebraskan, came from the Keewatin center and covered a large area in the Mis-

[2] Kay, G. F., History of Investigations and Classifications of the Pleistocene Deposits of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 70-133, 1929.

[2a] Kay, G. F., Classification and Duration of the Pleistocene Period: Bull. Geol. Soc. of America, Vol. 42, pp. 425-466, 1931.

Kay, G. F., and Leighton, Morris M., Eldoran Epoch of the Pleistocene Period: Bull. Geol. Soc. of America, Vol. 44, pp. 669-674, 1933.

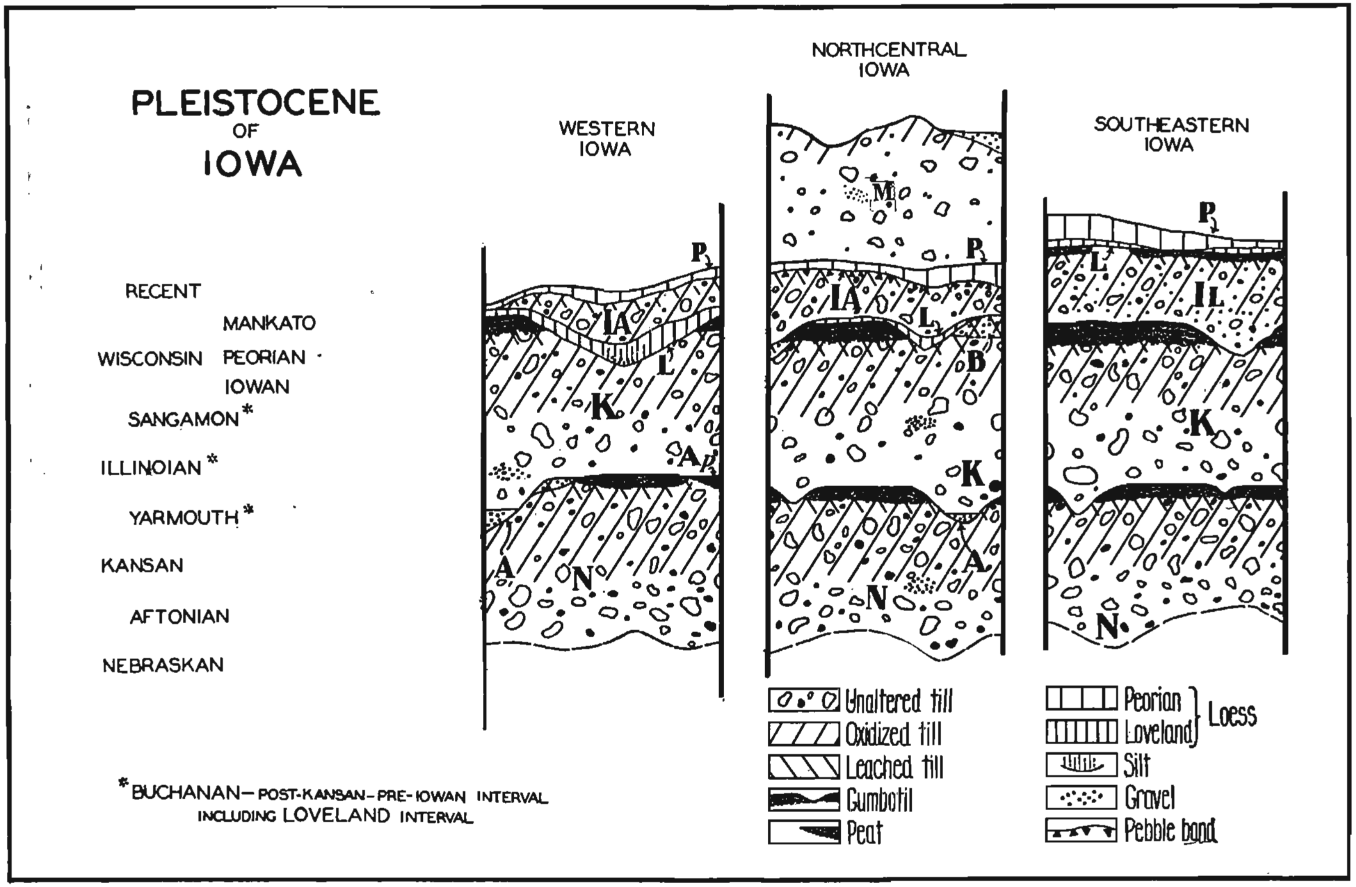


Fig. 1. — Diagrammatic sections of glacial and interglacial materials in the Pleistocene of Iowa.

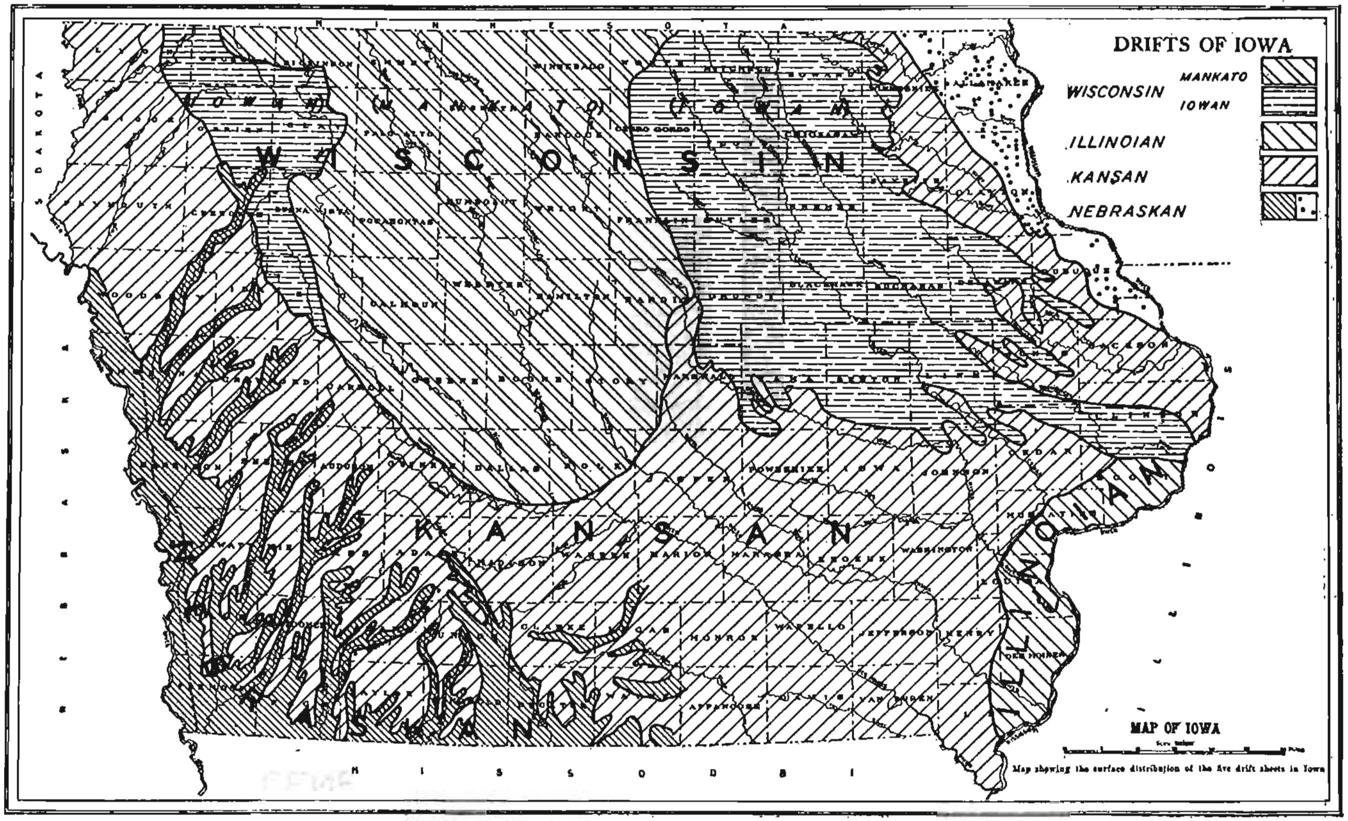


Fig. 2. — Map showing the surface distribution of the drift sheets of Iowa.

sissippi Valley. The evidence suggests strongly that this oldest ice sheet advanced over an area on which had been developed a topography characteristic of a mature erosional surface, with broad valleys, moderate slopes, and complete drainage systems. The drift left by this ice sheet has been estimated to have had a thickness of more than 100 feet, possibly as much as 150 feet. The drift consists of boulder clay or till with associated sands and gravels. This Nebraskan drift is at the surface in restricted areas only (see figure 2), as it is overlain in many places by younger drifts. The evidence as revealed in Iowa and adjacent states indicates that when the Nebraskan ice withdrew there was left over large areas a comparatively flat, poorly drained ground moraine plain. Till was the material left most widely at the surface of this plain; in places on the plain were sands and gravels. During the Aftonian interglacial age this drift underwent important changes. The unoxidized and unleached Nebraskan till, where so situated that chemical weathering was effective and erosion was negligible, was changed stage by stage until Nebraskan gumbotil was developed to an average thickness of more than 8 feet. Where gravels were subjected to weathering throughout Aftonian time — under topographic conditions similar to those under which gumbotil was developed from till — these gravels underwent great chemical changes also, changes comparable to those which the till underwent in the formation of gumbotil. In fact, in places in Iowa upland Nebraskan gravels are known which during Aftonian time were thoroughly leached of their calcium carbonate to a depth of 20 feet. Lenses and irregular masses of gravel incorporated in the Nebraskan till are only slightly weathered. In places peat instead of gumbotil was formed on the Nebraskan ground moraine plain. After the development of gumbotil much of the Nebraskan ground moraine plain was eroded, leaving only remnants of the former widespread Nebraskan gumbotil plain, and in places within the eroded areas sand and gravel were deposited.

The record of the weathering of the Nebraskan drift is well preserved in many places in Iowa because the gumbotil and related materials were covered by the drift of the second ice sheet, the Kansan. In the slopes of valleys, in road and railroad cuts, and in other excavations which go below the old Nebraskan surface, there are exposures of the Nebraskan gumbotil and underlying zones. In places the Nebraskan drift was all eroded before the coming of the Kansan ice sheet;

elsewhere the Kansan glacier removed only a part of the Nebraskan drift. Under such conditions the upper part of the Nebraskan drift is absent, and where the remaining Nebraskan drift is overlain by Kansan drift it is difficult to distinguish one drift from the other.

Kansan Drift and Related Materials

The second epoch (series), the Ottumwan, began with the advance of the Kansan ice sheet and ended with the oncoming of the Illinoian. It includes the Kansan glacial age (stage) and the Yarmouth interglacial age (stage). The Kansan drift sheet covered a large area in the Mississippi Valley. This drift has been estimated from field evidence to have had an average thickness, above the Nebraskan gumbotil plain, of about 50 feet. When to this figure is added the material necessary to fill the valleys cut in the Nebraskan drift the Kansan is seen to be also a massive drift to be ranked with the Nebraskan as one of the great drift sheets of the Pleistocene. During the Yarmouth interglacial age the Kansan drift underwent changes similar to those to which the Nebraskan drift was subjected in Aftonian time. That is to say, on the flat, poorly drained, Kansan ground moraine plain there was developed a gumbotil with maximum thickness of about 15 feet and average thickness of more than 11 feet. Gravels of Kansan age, where they were subjected to weathering under conditions similar to those under which Kansan till was being changed to gumbotil, became strongly oxidized and leached. In places, these upland Kansan gravels were leached to a depth of about 30 feet during Yarmouth interglacial time. As in the case of the Nebraskan, after the development of gumbotil and related weathered materials on the Kansan ground moraine plain, this plain was considerably eroded, leaving only remnants of the former widespread Kansan gumbotil plain, the largest of which are in southern Iowa and northern Missouri. In places within the eroded areas, sands and gravels were deposited, and in places loess was deposited before the deposition of the Illinoian drift.

In many places in Iowa and adjacent states, the Nebraskan and Kansan drifts closely resemble each other. Only locally can the Nebraskan drift be differentiated lithologically from the Kansan drift. In fact, the only satisfactory basis found thus far on which to decide definitely whether a pre-Illinoian drift is Nebraskan or Kansan is the relationship of the drift to interglacial materials whose age can be

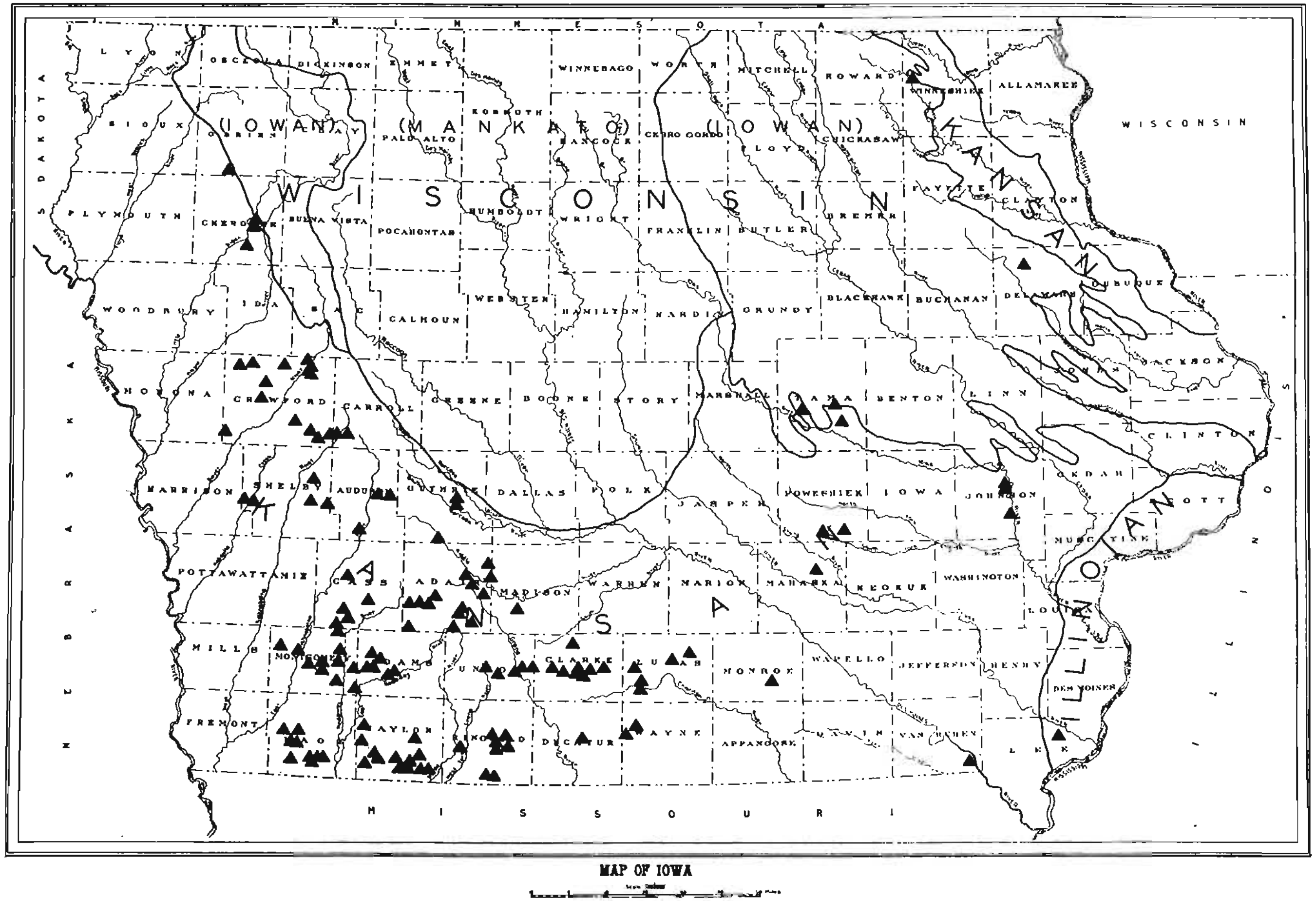
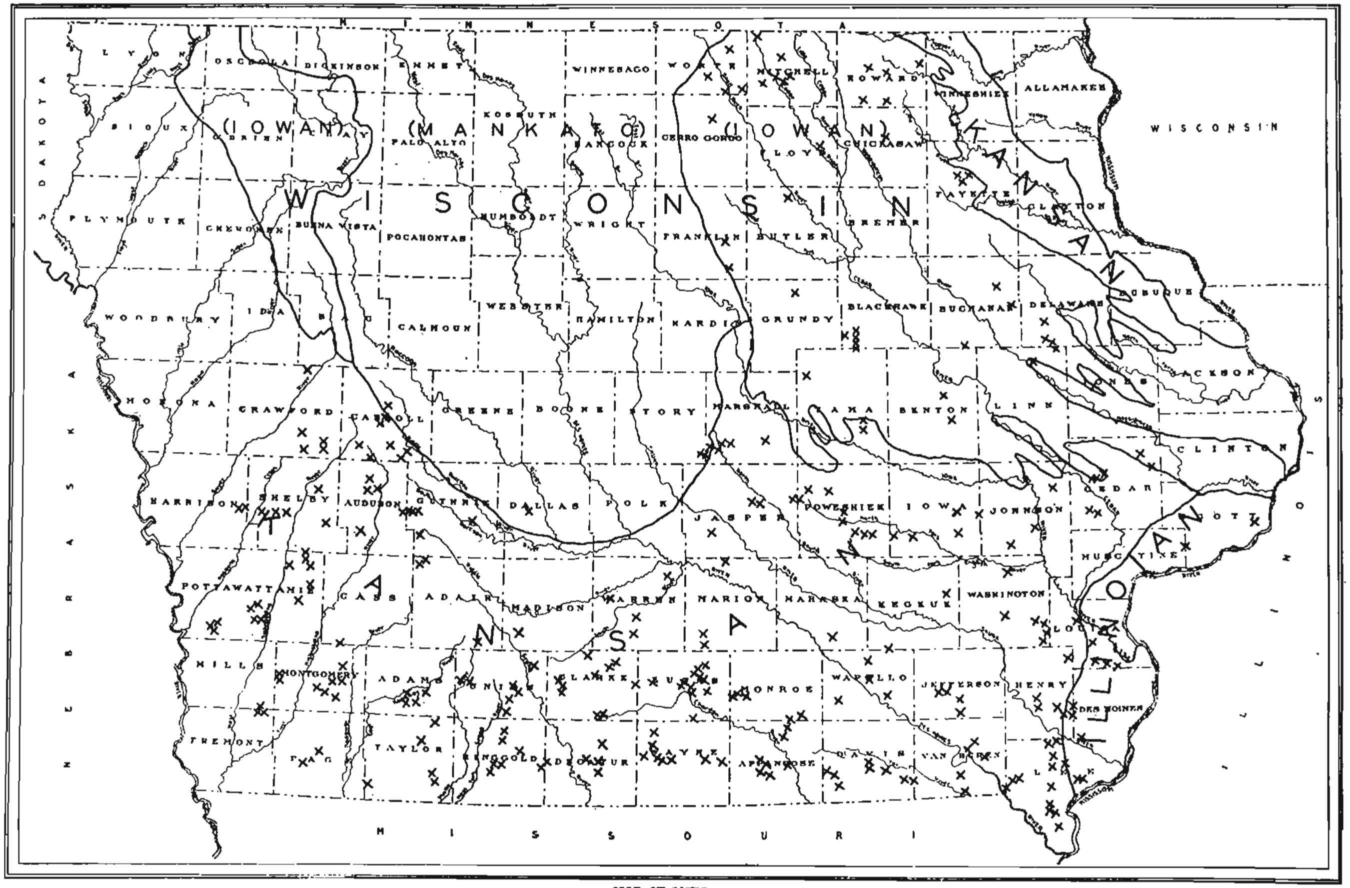


FIG. 3. — Locations of Nebraskan gumbotil outcrops in Iowa. The gumbotil, indicated by triangles, is the chief Aftonian interglacial horizon marker in the State.

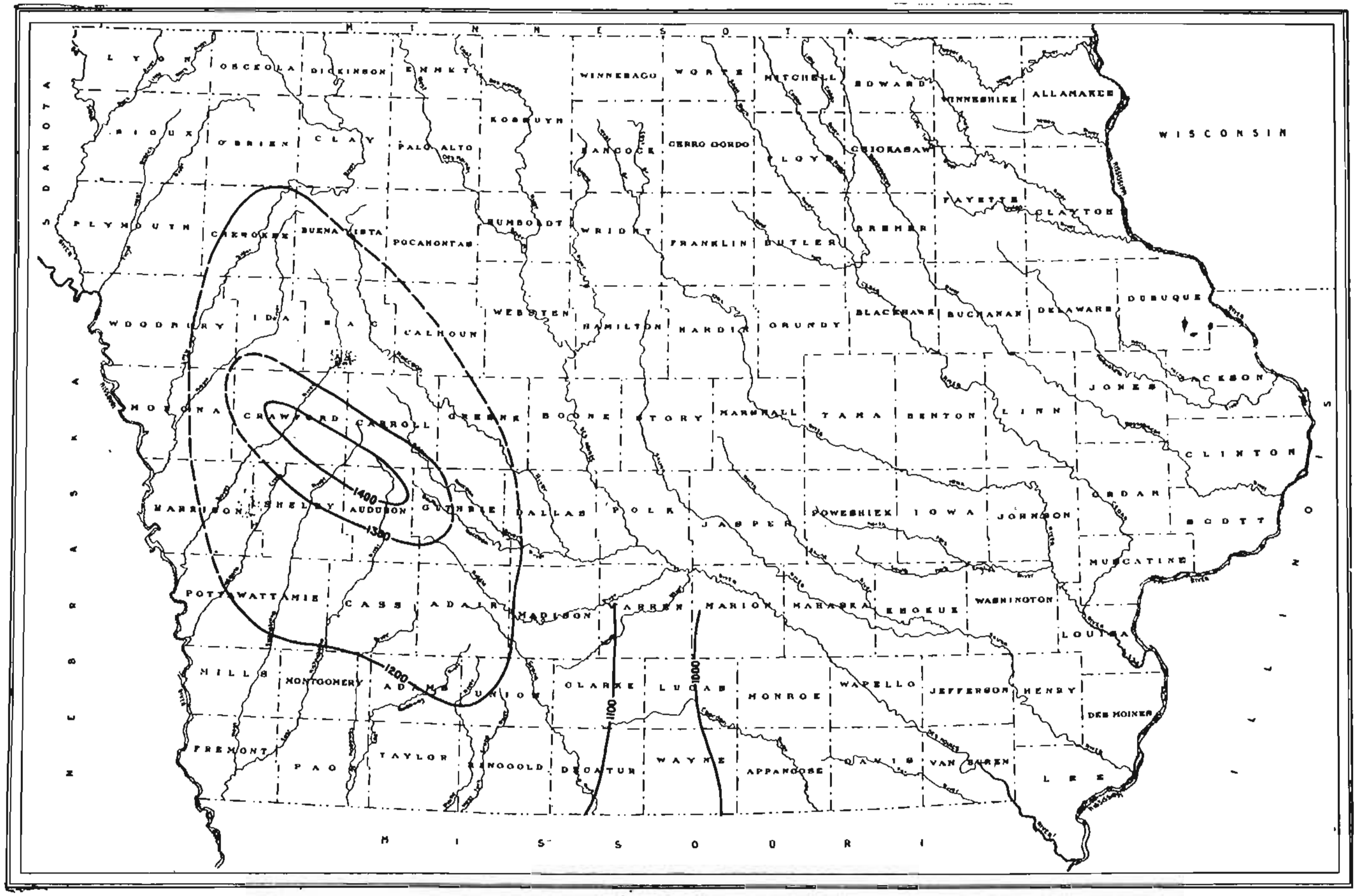


MAP OF IOWA

Fig. 4. — Locations of Kansan gumbotil outcrops in Iowa. The gumbotil indicated by crosses, is the chief Yarmouth interglacial horizon marker in the State.

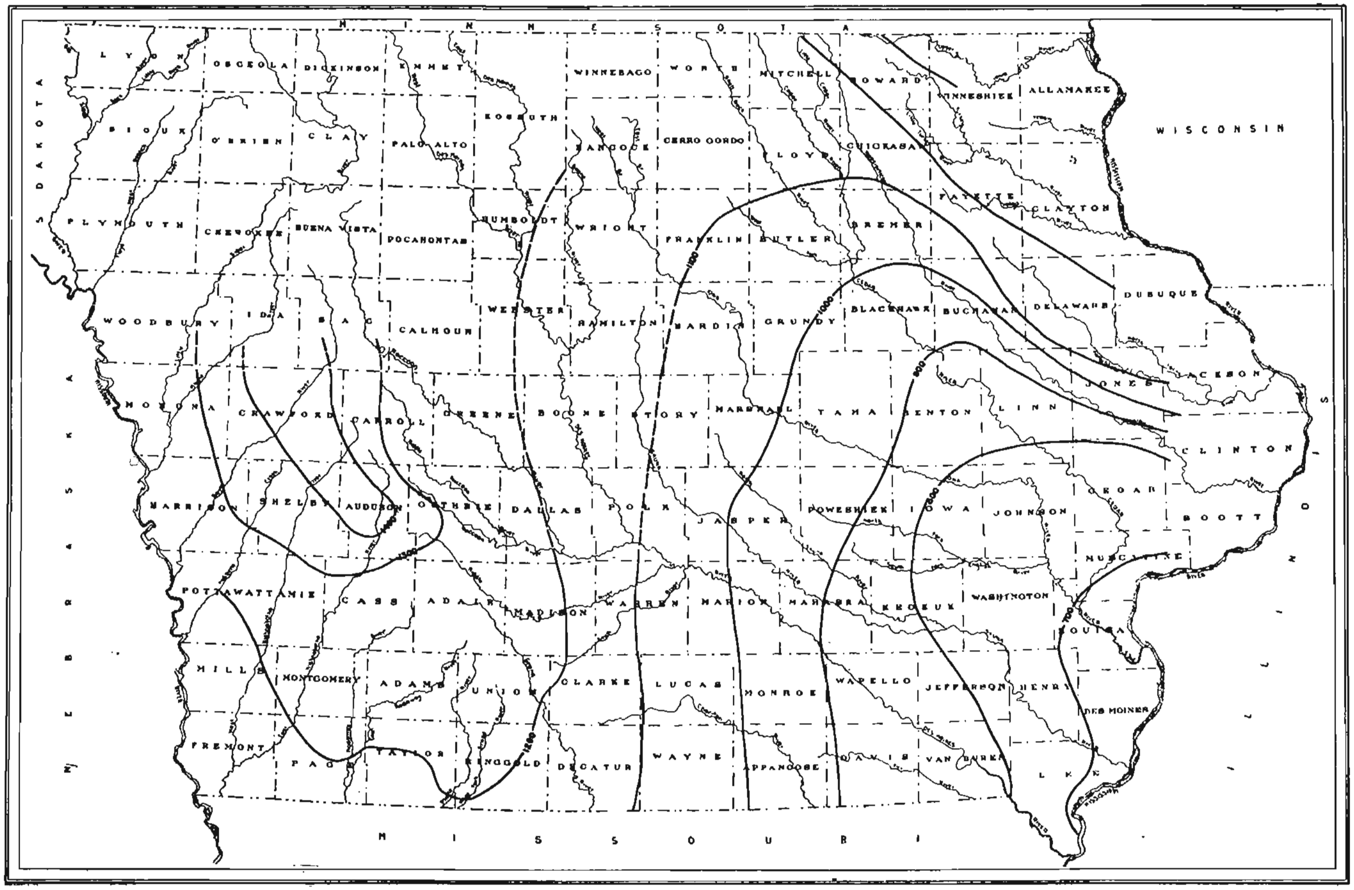
determined. Among the most widespread of interglacial materials separating Nebraskan from Kansan till is gumbotil. If a till is overlain by Nebraskan gumbotil or can be shown to be related to Nebraskan gumbotil, which in Iowa is found as remnants of a former extensive Nebraskan gumbotil plain, it is Nebraskan till. If, however, the till is overlain by a gumbotil which is known to be a remnant of the former extensive Kansan gumbotil plain the till is Kansan till. In fact, the gumbotils, on account of their distinctive characters, wide distribution, and topographic positions are the most satisfactory criteria that have been found for differentiating the older drifts. They have proved to be the most satisfactory Aftonian and Yarmouth horizon markers. They have been useful especially in differentiating and mapping the Nebraskan and Kansan drifts over wide areas. Figure 3 shows outcrops of Nebraskan gumbotil of Aftonian age separating Nebraskan till from Kansan till in Iowa, and figure 4 shows outcrops of Kansan gumbotil of Yarmouth age. From these outcrops it is possible to map areally the Nebraskan and Kansan drifts. Moreover, the Nebraskan gumbotil outcrops and the Kansan gumbotil outcrops mark the positions of the surfaces of the ground moraine plains on which the gumbotils were formed. From the altitudes of these outcrops it is possible also to construct maps to show the altitude of the Nebraskan and Kansan till surfaces during Aftonian and Yarmouth ages, respectively (see figures 5 and 6).

Peats and weathered gravels have been and will continue to be of value in interpreting Aftonian and Yarmouth interglacial history, but they have been found to be less serviceable than the gumbotils in areal mapping. Only a few good peat exposures of Aftonian age have been found in the Mississippi Valley and these are widely separated from one another. There are few known good exposures of peat of Yarmouth age. Moreover, since gravels differ in origin, in composition, in topographic position, in degree of weathering, and in other respects, their use in mapping is somewhat restricted. Much less reliance is now placed on interpretations of gravels and 'forest beds' penetrated in well drillings than was given to these materials in the earlier years of Pleistocene studies. Loess of late Yarmouth age is present in places in Illinois and Iowa.



MAP OF IOWA

FIG. 5. — Contour map of Nebraskan plain, showing the surface of the Nebraskan plain in western Iowa on which gumbotil was formed during Aftonian time. Contour interval, 100 feet.



MAP OF IOWA

FIG. 6. — Contour map of Kansan plain, showing the surface of the Kansan plain on which gumbotil was formed during Yarmouth time. Contour interval, 100 feet.

Illinoian Drift and Related Materials

The third epoch (series), the Centralian, began with the recurrence of glacial conditions, which resulted in the third ice sheet and ended with the oncoming of the Iowan ice sheet. It included the Illinoian glacial age (stage) and the Sangamon interglacial age (stage).

The Illinoian ice sheet came into Iowa from the Labradorean center. The drift left by this ice sheet is exposed widely in Illinois, Indiana, and Ohio. A lobe of the Illinoian ice extended into southeastern Iowa, displacing the Mississippi river from its present location westward to a position where it remained until post-Illinoian time. The Illinoian drift, which has an average thickness of about 30 feet, has the same general characters as the Nebraskan and Kansan drifts. Extensive areas of its surface are flat and uneroded. In limited areas the topography is distinctly morainic. During the Sangamon interglacial age Illinoian till was weathered to a gumbotil to a depth of 4 to 6 feet where the topographic conditions were similar to the topographic conditions under which gumbotil was developed on the Nebraskan and Kansan tills.

Within the Illinoian drift area there are in many places two loesses on the Illinoian gumbotil and on eroded surfaces of Illinoian drift. The younger of these two loesses is the Peorian loess; the older loess has been correlated by the senior author with the widespread Loveland loess of western Iowa, which is later than the Kansan gumbotil erosion and is pre-Iowan in age. Leverett, however, correlates the Loveland loess of western Iowa with pre-Illinoian loess and questions the existence of a post-Illinoian, pre-Peorian loess. But in recent years this older loess on the Illinoian has been mapped widely by members of the Illinois and Iowa Geological Surveys. Although the Loveland loess of western, central, and southern Iowa outside the limits of the Illinoian area appears to be a single formation which was deposited in post-Illinoian, pre-Iowan time, the senior author has stated that in reality its lower part may be pre-Illinoian in age, and only its upper part post-Illinoian; and it may be that a part of the Loveland loess where it lies on drift older than the Illinoian was deposited during the Illinoian glacial age. The older of the two loesses on the Illinoian drift has been referred to late Sangamon time by the geologists of the Illinois Survey.

The Iowan Drift, the Peorian Loess, and the Mankato Drift

The youngest epoch (series), the Eldoran, began with the coming of the Iowan ice sheet and ended with the retreat of the Mankato. In Iowa it includes the Iowan glacial, the Peorian intraglacial, and the Mankato glacial substages of the Wisconsin age (stage).

The Iowan drift is limited in distribution and its characteristics are best known from studies in northeastern Iowa. The Iowan is thin, having an average thickness of less than 10 feet. Its topography is a drift-mantled, erosional type, although the mantle is in places thick enough to produce distinctly depositional features. In parts of the area the relief is very slight and the surface appears to the eye to be almost level. In Iowa, the Iowan was deposited on Kansan gumbotil, on the eroded surfaces of the Kansan drift, or on Loveland loess. Since the retreat of the Iowan there has not been sufficient time for the development of gumbotil. However, leaching of calcium carbonate has proceeded to a depth of somewhat more than 5 feet.

In recent years Leverett has contended that the Iowan is a Keewatin phase of the Illinoian. However, Kay, Alden and Leighton, and other geologists have presented evidence to show that the Iowan is much more closely related in age to the Wisconsin than to the Illinoian. Kay has contended also that the Sangamon interval, which separates the Iowan and the Illinoian glacial ages, was much longer than the Peorian interval — long enough for gumbotil more than 3 feet thick to have been developed on the Illinoian till, also for post-Illinoian gumbotil erosion, also for the deposition of a loess on this eroded Illinoian and for weathering of the loess all before the close of Sangamon time.

The Peorian intraglacial age was characterized by widespread loess deposition. This loess was apparently laid down shortly after the deposition of the Iowan drift. It varies in thickness from a few feet to nearly 100 feet adjacent to wide floodplains. In places, this loess is apparently genetically related to the Iowan. The senior author [8] has shown that the depth of leaching of the Peorian loess in Iowa where it is not overlain by Mankato drift is about the same as the depth of leaching of the Iowan till which has been subjected to leaching since the retreat of the Iowan ice sheet from Iowa. The presence of a pebble

8 Kay, G. F., The Relative ages of the Iowan and Wisconsin Drift Sheets: Amer. Journ. of Science, Vol. 21, pp. 158-172, 1931.

band on the Iowan drift beneath the Peorian loess is one of the arguments advanced by Leverett for the interpretation that the Peorian loess is much younger than the Iowan — the Iowan being considered by him to be comparable to the Illinoian.

The youngest of the drifts is the Mankato. It retains the distinctive features of youth such as moraines, eskers, kames, and lakes. The depth of leaching since the retreat of this ice sheet from Iowa has been determined to be about 30 inches.

PREVIOUS INVESTIGATIONS OF THE PLEISTOCENE GRAVELS OF IOWA

General Statement

As early as 1870, C. A. White referred to pockets of sand and gravel in till in Iowa.[4] Since that time many papers have been published in which sands and gravels of Pleistocene age have been described. The county reports of the present Iowa Geological Survey contain many general facts regarding the sands and gravels which are found in the different parts of the state. These sands and gravels have been described by Beyer [5] and by Wood [5a] also, but chiefly as economic materials. The two best known ages of gravels of the state are those described as Aftonian gravels of the Afton Junction-Thayer region and of western Iowa, and the Buchanan gravels of northeastern Iowa.

Chamberlin's Investigations at Afton Junction

In the year 1893, Chamberlin and McGee visited the Afton Junction-Thayer region in Union county, Iowa, where they examined the now famous exposures of tills and gravel. They interpreted the chief gravels to be kamelike deposits closely associated with the till upon which they lie.[6] Only at the Grand River pit was till exposed beneath these gravels. The till which lies on the gravels was considered by Chamberlin and McGee to have been deposited in connection with the second ice invasion. And now for the first time names were given to tills of different ages in Iowa. Chamberlin named the older of the two tills in the Afton Junction-Thayer region the Kansan, and the younger till the East Iowan. He believed that these two tills were of the same age as McGee's Lower Till and Upper Till, respectively, which had been mapped areally in northeastern Iowa. At this time no name was given to the gravel separating the Kansan till from the East Iowan till in the Afton Junction region or to the forest beds, peats, and soils, which in many places in Iowa were known to separate

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4 White, C. A., Report on the Geological Survey of the State of Iowa: Vol. I, pp. 82-102, 1870.
5 Beyer, S. W., The Road and Concrete Materials of Iowa: Iowa Geol. Survey, Vol. XXIV, pp. 33-685, 1914.
5a Wood, L. W., The Road and Concrete Materials of Southern Iowa: Iowa Geol. Survey, Vol. XXXVI, 14-310, 1935.
6 Chamberlin, T. C., in James Geikie's The Great Ice Age, pp. 724-774, 1894.

two tills and were interpreted to be the products of the first interglacial age. But in 1895, Chamberlin again referred to the gravels and used for the first time the name Aftonian for the interglacial interval separating the Kansan till from the Iowan till.[7] His statement is as follows:

"Subsequent to the formation of the Kansan sheet of till and accompanying assorted deposits there was a notable retreat of the ice. . . . During this stage of retreat there were accumulations of muck and peat reaching a reported depth of twenty-five feet. One of the best exposures of this horizon is found between Afton and Thayer, Iowa, and from the former a euphonious name may be taken. Owing to the scarcity of gravel in the drift territory of southern Iowa the Chicago, Burlington & Quincy Railroad has made extensive excavations upon these gravel deposits lying between an upper sheet of till reaching a thickness of 40 to 60 feet and a lower till of less depth. The gravels appear to be kamelike accumulations, at least they are great lenses lying upon the surface of the lower till. This lower till is believed to belong to the Kansan stage and the upper to the Iowan. On the surface of the gravels there accumulated at points a deep mucky soil, in which occur considerable quantities of vegetable debris. This is believed to occupy the same horizon as the numerous peaty deposits described by McGee in eastern Iowa."

From this statement it is evident that the term Aftonian as first used was applied only to the horizon represented by soil bands, peat, and muck, and was correlated with the forest bed of McGee. According to the classification of Chamberlin's paper, the name Kansan was used for the lower till and the name Iowan for the upper till in the Grand River pit. The Aftonian beds proper were considered to have been deposited in the interval separating the two tills.

Calvin's Interpretations of Buchanan Gravels

In 1896, Calvin[8] published a paper on the Buchanan gravels. He stated:

"While, therefore, the gravels lie between two sheets of drift and for that reason may be called interglacial, probably Aftonian, they yet belong to the time of the first ice melting, and are related to the Kansan stage of the glacial series as the loess of northeastern Iowa is related to the Iowan stage."

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7 Chamberlin, T. C., The Classification of American Glacial Deposits: Journal of Geology, Vol. III, pp. 270-277, 1895.

8 Calvin, Samuel, The Buchanan Gravels; an Interglacial Deposit in Buchanan County, Iowa: Amer. Geol., Vol. XVII, pp. 76-78, 1896.

About this time the classification of the Pleistocene deposits in the Afton Junction region was revised by naming the lower till pre-Kansan instead of Kansan and the upper till Kansan instead of Iowan. The reasons for these changes have been discussed fully in a paper by the senior author.[9]

Calvin soon recognized that the Buchanan gravels separated the Kansan till from Iowan till in northeastern Iowa, and hence were not Aftonian in age. In his report on Buchanan county, in Volume VIII of the reports of the Iowa Geological Survey, he described these Buchanan gravels. He referred to an upland phase in which the materials are relatively coarse and a valley phase in which they are composed largely of sand and fine gravel. In his report on Howard county, in Volume XIII, he referred again to the upland and valley phases of the Buchanan gravels and expressed the view that the upland gravels were deposited by streams flowing on the higher areas which had become bare while bodies of ice yet filled the valleys and lowlands. Then after the ice melted from the valleys the gravels there were laid down.

Calvin's Interpretation of the Gravels of the Afton Junction Region

Between the years 1900 and 1905 the Chicago, Burlington and Quincy Railroad made some important changes in the road between Thayer and Afton in Union county, in connection with which numerous deep cuts in drift were made, affording an unusual opportunity for the study of the glacial deposits. These new cuts as well as the Afton Junction, Grand River, and Thayer gravel pits were studied carefully by Calvin. The results of his investigations were given in a paper published by the Davenport Academy of Science.[10] In this paper, on page 21, he stated:

"There are three possibilities: (1) the gravels may have been laid down along drainage courses by waters flowing away from the melting and retreating margin of the pre-Kansan ice, upon a surface which but a short time before had been left bare by the gradually waning glaciers . . . (2) The gravels may have been deposited by waters flowing out in front of the advancing Kansan ice, in which case they were laid down upon the eroded and weathered surface of the pre-Kansan till. . . . (3) The gravels

9 Kay, G. F., History of Investigations and Classifications of the Pleistocene Deposits of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 70-133, 1929. (Preprint 1928)
10 Calvin, Samuel, The Aftonian Gravels and their Relations to the Drift Sheets in the Region about Afton Junction and Thayer: Davenport Acad. Sci., Vol. X, pp. 18-31, 1905.

may have been deposited by floods which were in no way related to glacial conditions, and these floods may have occurred at any time during the long interval of mild climate which separated the pre-Kansan glacial stage from the Kansan."

In discussing these three possibilities, Calvin pointed out that the drift sheets related to the gravels differ in their petrological content. For example, the Kansan drift is much richer in quartzites and greenstones; the pre-Kansan is richer in granites. Furthermore, he stated, on page 22:

"The coarse feldspathic granites of the sub-Aftonian till are common among the cobbles and pebbles of the Aftonian deposit, while greenstones and basalts are relatively scarce. . . . Another fact of great significance is found in the highly ferruginous and profoundly weathered zone immediately below their contact with the overlying Kansan till."

Thus, the author concluded that the evidence supported the view that the Aftonian gravels were in place and profoundly weathered before the deposition of the Kansan drift, and hence the second hypothesis which would relate the gravels to the Kansan drift was untenable.

In discussing the third hypothesis he stated:

"It may be enough to say that, so far as relates to the interval between the complete melting of the pre-Kansan and the incursion of the Kansan ice, there is no way at present known to account for floods of volume and duration sufficient to transport and deposit the great beds which make up the Aftonian formation."

That Calvin considered the evidence conclusively in favor of the view that the Aftonian gravels were deposited in connection with the retreat of the pre-Kansan ice sheet is indicated in the following quotation:

"In the analogous case of the Buchanan gravels so extensively distributed throughout northeastern Iowa, there are indications which point unquestionably to their transportation and deposition by great floods liberated by the melting of the Kansan glaciers. The melting of the pre-Kansan glaciers certainly gave rise to similar floods, and it is safe to assume that these were the agents whereby the Aftonian gravels were carried and deposited."

In the concluding part of his paper, on page 29, Calvin made the following very definite statement:

"That the Aftonian was a real interglacial interval of mild climate and of long duration, is demonstrated by the evidence of extensive peat beds and forests which developed on the surface of the pre-Kansan drift, and were later overwhelmed and buried by the glaciation of the Kansan stage."

This conclusion, it will be noted, is based not upon the evidence furnished by the gravels, but rather upon the existence of peat and forest beds which had been found in other localities.

Although in the paper to which reference has just been made the judgment of Calvin is very positive with regard to the close relation of the gravels to the pre-Kansan drift, it will be found, if his subsequent papers are read, that he modified his view regarding the origin of the gravels. This change of view was not the result of further field study of the gravels in the Afton Junction-Thayer region, but of some interesting studies by Professor Shimek and himself of gravels in western Iowa and the fossils which they contain. Professor Shimek in the summer of 1908 found fossiliferous sands and gravels in western Iowa, chiefly in Harrison and Monona counties, which he classified as Aftonian gravels of strictly interglacial origin. In a paper in which he described the sands and gravels [11] he discussed their relations to the drifts as follows:

"(1) They are not sub-Aftonian because in every case examined they lie unconformably on the older drift, the old oxidized and weathered surface of which sharply marks the line of division between the two deposits. (2) They are not Kansan, for in nearly all the exposures Kansan is shown clearly resting unconformably on them, with calcareous plates (nodular) cementing sands and gravels, and strongly oxidized material sharply defining the line of division. Moreover, evidence is furnished by several exposures that the Kansan passed over the Aftonian beds while the latter were frozen, and plowed and tilted them in mass or disturbed and folded them in intricate fashion. (3) The sand and gravel beds are not glacial, but interglacial. That the materials were deposited in streams is shown by the fact that they are water-worn, cross-bedded with frequent interbedding of sand and gravel, the latter deposited by stronger currents, and that they contain fluviatile shells, with such intermingling of land shells as is common in the same region in modern alluvial deposits. That the climate was mild during this interglacial period is shown by the presence of the large numbers of herbivorous mammals which required a vigorous flora for their maintenance, and of fresh water and land mollusks, which are

[11] Shimek, B., Aftonian Sands and Gravels in Western Iowa: Bull. Geol. Soc. of Amer., Vol. 20, p. 406, 1909.

identical with species now living in Iowa. The aquatic shells suggest the same biotic conditions as exist in the state today, and the land shells required plant-covered land surfaces on which they could find food and shelter, and these surfaces are not radically different from those which prevail in Iowa today, if we are to judge from the identity of the land forms."

Calvin studied the mammalian remains which were taken from the Aftonian gravels in western Iowa, and in one of his papers [12] he made reference to the gravels and their contained fauna as follows:

"The stratigraphic position is clear and well established; the gravels are Aftonian in age, but they contain evidence that they were not deposited until some time after the old pre-Kansan ice sheet had completely disappeared. The new evidence comes in the form of a fairly rich mammalian fauna that must have been contemporary with the deposition of the gravels, but which certainly did not live in the wet, chilly, verdureless region that co-existed with the melting of the pre-Kansan ice."

This same view was emphasized strongly in a paper by Calvin published in 1910.[13] Shimek also presented evidence for the view that the fossiliferous gravel and sand beds of western Iowa are Aftonian.[14]

These conclusions with regard to the gravels in western Iowa, and the fauna associated with them, naturally caused Calvin to be less sure than he previously had been regarding his interpretation of the origin of the Aftonian gravels in the Afton Junction, Grand River, and Thayer pits of Union county. In his Presidential address [15] read before the Geological Society of America he referred to the gravels of Union county as follows:

"The same gravels are exposed in a great ballast pit at Afton Junction, from which locality came the name 'Aftonian' given to the gravels as well as to the entire interval of which they form part of the record."

He called attention to Shimek's investigations in western Iowa, and stated that it might become necessary to modify the view expressed in 1905 in the Davenport Academy paper. He stated further that foot bones of a small, slender-limbed horse had been found in the Afton-Thayer deposits, and expressed the following judgment:

12 Calvin, Samuel, Aftonian Mammalian Fauna: Bull. Geol. Soc. of Amer., Vol. 20, pp. 341-356, 1909.

13 Calvin, Samuel, The Aftonian Age of the Aftonian Mammalian Fauna: Proc. Iowa Acad. Sci., Vol. XVII, pp. 177-180, 1910.

14 Shimek, B., Evidence that the Fossiliferous Gravel and Sand Beds of Iowa and Nebraska are Aftonian: Bull. Geol. Soc. of Amer., Vol. 21, pp. 119-140, 1910.

15 Calvin, Samuel, Present Phase of the Pleistocene Problems in Iowa: Bull. Geol. Soc. of Amer., Vol. 20, pp. 133-152, 1909.

"In the light of new finds in Harrison and Monona counties we may conclude that this beautiful little Equus was probably contemporary with the deposition of the gravels."

In this same paper, in concluding his discussion of the Aftonian, he stated:

"All lines of evidence now indicate that the beds in question record conditions which existed at some time during the progress of the interval, neither at its beginning nor at its close, but in the light of present knowledge the precise age of the deposits cannot be more definitely stated."

Kay's Interpretation of the Gravels of the Afton Junction Region

Kay after a detailed study of the sands and gravels in the Afton Junction region made the following statement: [16]

". . . The two tills of the region are now called the Nebraskan till and the Kansan till, and the gravels separating these tills have long been called the Aftonian gravels. It may be well to restate here that Chamberlin interpreted the chief gravels separating the two tills to be kamelike deposits on the surface of the lower till (present Nebraskan till) and related in age to this till. The gravels became much weathered during the Aftonian interval. Bain referred to evidence of lateral transition from gravels into boulder clay and suggested the possible contemporaneity of the gravels with the upper till (present Kansan till). Calvin, in 1905, interpreted these gravels to be deposits made by torrential floods during the retreating stages of the pre-Kansan ice. Later, in 1908, chiefly as a result of studies by himself and Shimek of gravels and their included fossil faunas in western Iowa, he suggested modification of his former view of the Aftonian gravels. He expressed the judgment that the most satisfactory interpretation of the gravels was that they are interglacial in age, having been deposited during the progress of the Aftonian interval, neither at its beginning nor at its end.

"Recent studies of the gravels and their relationships to the tills in the Afton Junction-Thayer region justify the statement that the chief gravels of Union county, which were thought by Calvin to have been deposited within the Aftonian interglacial epoch and to constitute a distinct stratigraphic horizon separating the Kansan till from the Nebraskan till, are not of this origin or age. Rather, the chief sands and gravels are lenses and irregularly shaped masses of gravels in the Nebraskan till and contemporaneous in age with that till. They are gravels not of Aftonian age but of Nebraskan age. They lie in large part below the level of the rem-

16 Kay, G. F., History of Investigations and Classifications of the Pleistocene Deposits of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 123-125, 1929. (Preprint 1928)

nants of Nebraskan gumbotil within this area. However, in a few places, as for example, in the Afton Junction pit close to Afton Junction station, the Nebraskan gravels in some places and the Nebraskan till in other places are at the surface of the Nebraskan drift. During the Aftonian interglacial interval the upper part of the Nebraskan till became weathered to Nebraskan gumbotil and the Nebraskan gravels which had a similar topographic relation to the Nebraskan till became weathered to highly oxidized and leached gravels. There are gradations laterally from typical Nebraskan gumbotil to gumboized gravels to thoroughly leached gravels. Later, both Nebraskan gumbotil and the oxidized and leached Nebraskan gravels were overlain by Kansan drift. Some of the Nebraskan gumbotil and some of the weathered gravels were picked up by the Kansan ice and are now inclusions in the Kansan till. Since the Nebraskan gravels which were weathered while at the surface and which now separate the Nebraskan till below from the Kansan till above underwent their great changes during the Aftonian interglacial epoch it may be considered proper to continue to call such gravels Aftonian gravels, but it is here suggested that the name Aftonian gravels be no longer used for the sands and gravels of Nebraskan age which were changed to their present condition in Aftonian time, but that they be called weathered Nebraskan gravels, just as the Nebraskan gumbotil is the name given to weathered Nebraskan till, the weathering having taken place in Aftonian time. The weathered Nebraskan gravels do in places separate Nebraskan till from Kansan till, and hence constitute the Aftonian stratigraphic horizon, just as peat does in some places in this area and in other areas. But Nebraskan gumbotil rather than gravels or peat is the most widespread evidence of Aftonian interglacial time in the Afton Junction-Thayer region. This Nebraskan gumbotil has been mapped over wide areas in southwestern Iowa and in other parts of the state and hence is the most significant Aftonian horizon marker which thus far has been found.

"The major interpretations of Chamberlin and McGee made many years ago in the Afton Junction-Thayer region have been strengthened by the recent studies, and this region will continue to be the classic area of Iowa for the investigation of the two oldest drifts, the Nebraskan and the Kansan, and of Nebraskan gumbotil, weathered Nebraskan gravels, and peat, which are the most distinctive evidences in support of the reality of the Aftonian interglacial epoch."

Kay's Interpretation of the Gravels of Western Iowa

In the year 1924, the senior author made the following statement regarding the sands and gravels of western Iowa:[17]

17 Kay, G. F., Recent Studies of the Pleistocene in Western Iowa: (Abstract), Bull. Geol. Soc. of Amer., Vol. 35, pp. 71-74, 1924.

"The sands and gravels of western Iowa, which were described by Shimek and Calvin as being Aftonian interglacial gravels separating the Nebraskan till from the Kansan till and related in origin neither to deposits made during the closing stages of the Nebraskan glacial epoch nor to deposits made during the Kansan glacial epoch, are thought by the writer not to represent a distinctive stratigraphic horizon separating the Nebraskan till from the Kansan till. But instead they are interpreted as being lenses and irregularly shaped masses of gravels and sands within a single till; or, if in two tills, it is not possible to use the gravels and sands as evidence for differentiating these two tills. The gravels and sands are unleached and appear to be contemporaneous in age with the tills with which they are associated.

"Many mammalian fossils have been found in the sands and gravels associated with the tills of western Iowa. Calvin and Shimek believed that these remains were of animals which were living during the time of deposition of the gravels, which they interpreted as Aftonian and interglacial. But if the sands and gravels are lenses and irregularly shaped pockets related in age to the till with which they are associated, then a somewhat different interpretation of the age of the mammals becomes necessary. At the present time it is impossible to state whether the gravels in which the mammalian remains have been found are associated with Nebraskan till or with Kansan till, since, as stated previously, it has not been possible thus far to differentiate Nebraskan till from Kansan till except where the relationships of the till to gumbotil, the age of which is known, have been established. If the gravels in which the mammalian remains have been found should prove to be lenses and pockets in Nebraskan till, then the evidence would suggest that the animals are Nebraskan in age. It would be reasonable to assume that the animals were living in front of the advancing Nebraskan ice sheet, out from which sands and gravels were being carried. Remains of mammals became imbedded in the sands and gravels, which themselves later were overridden by or became incorporated in the onward moving Nebraskan till. If, on the other hand, the sands and gravels containing the mammalian remains should prove to be lenses and pockets in Kansan till, then the suggested interpretation would be that the mammals were living on the Aftonian surface during the advance of the Kansan ice sheet, out from which sands and gravels were being carried. After remains of mammals became imbedded in these sands and gravels the Kansan ice sheet advanced and incorporated in Kansan till these masses of sands and gravels in which the remains are found. If these conclusions are justified, then this mammalian fauna may not be a strictly interglacial fauna of Aftonian age. It is important to note, however, that the fauna is certainly early Pleistocene — that is, it was closely associated either with the advance of the Nebraskan ice or with the advance of the Kansan ice sheet, or it was associated with both as a result of having persisted on the adjacent plains from Nebraskan through Aftonian to Kansan time."

In 1929, Kay made a further statement with regard to the sands and gravels of western Iowa, as follows: [18]

"The sands and gravels in western Iowa which were interpreted by Shimek and Calvin to be Aftonian in age chiefly on account of the presence in the gravels of remains of mammals which they believed could have lived only in an interglacial epoch, are thought to be not interglacial but chiefly contemporaneous in age with the till with which the gravels are closely associated, the age of the till being probably Nebraskan but possibly Kansan. Some of the gravels may have been deposited in valleys in the Aftonian interglacial epoch, but their characteristics and their relationships to the till do not seem to support this view. Mammalian remains in the gravels do not of themselves determine whether the gravels are strictly interglacial in age or are of glacial origin, since vertebrate paleontologists are not in agreement regarding the climatic conditions under which mammals such as have been found in these gravels may live. Hay[19] is of the opinion that the mammals the remains of which have been found in the gravels of western Iowa could not have lived in the immediate vicinity of an ice sheet, but must have lived under interglacial climatic conditions. On the other hand, W. D. Matthew [20] believes that in determining the age of gravels and sands stratigraphic evidence can be more safely followed than fossil evidence. In a letter he stated:

> 'What actually seems to have happened in the Pleistocene was that glacial advances drove the boreal forms southward and compelled them to mingle temporarily with temperate faunas. . . . When the retreat of the ice opened up northern territory again, the boreal types were the first to extend their range northward, and then or later retreated from the southern territory they had invaded.'

"Matthew offers no adverse criticism to the view taken in this paper that the sands and gravels of western Iowa containing the remains of mammals were probably contemporaneous in age with the till with which they are apparently closely related in origin."

18 Kay, G. F., History of Investigations and Classifications of the Pleistocene Deposits of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 121-122, 1929. (Preprint 1928)
19 Hay, O. P., The Pleistocene of the Middle Region of North America and its Vertebrated Animals: Carnegie Institution, Washington, Publication 322A, 1924.
20 Personal communication.

Alden and Leighton's Interpretation of the Buchanan Gravels

As stated on page 25 of this report, Calvin recognized an upland phase and a valley phase of the Buchanan gravels in northeastern Iowa, both phases having been interpreted by him as being fluvio-glacial deposits of Kansan age. Alden and Leighton,[21] after a careful study of the gravels within the Iowan drift area of northeastern Iowa, concluded that the Buchanan gravels of the valley phase are glacial outwash of Iowan age rather than of Kansan age, and that there are upland gravels of two phases, one phase of Kansan age as interpreted by Calvin and the other phase of Iowan age. They referred to the two phases of upland gravels as Kansan kames and Iowan kames.

Schoewe's Lake Calvin Sands and Gravels

Schoewe in his report on Lake Calvin [22] described three lake terraces: an intermediate, a high, and a low terrace. The structure and materials of each of these terraces are discussed. The materials of the low terrace in contrast to the materials of the intermediate and high terraces are coarser, contain more gravel layers, have a higher textural range, and consist predominantly of sands with extremely little silt or clay. "Whereas the high and intermediate terraces contain thinly and horizontally bedded deposits with minor cross-bedding, the prevailing type of structure of the low terrace is well developed cross-bedding and pocket-and-lens stratification."

Carman's Interpretation of the Gravels of Northwestern Iowa

Two comprehensive reports have been prepared by Dr. J. E. Carman on the Pleistocene deposits of northwestern Iowa.[23,24] Reference will be made here only to his discussion of the gravels and sands in the later of these two reports. In this report sands and gravels have been differentiated and described as follows:

1. *Interbedded Gravel and Till.* With reference to these deposits Carman states: "An interbedding of gravel and till characterizes several exposures within the Iowa region. These deposits were formed by oscillations

21 Alden, W. G., and Leighton, Morris M., The Iowan Drift, A Review of the Evidences of the Iowan Stage of Glaciation: Iowa Geol. Survey, Vol. XXVI, pp. 49-212, 1917.

22 Schoewe, W. H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 49-222, 1924.

23 Carman, J. Ernest, The Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXVI, pp. 233-445, 1917.

24 Carman, J. Ernest, Further Studies of the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 15-193, 1931.

of the ice front during the general stages of advance and retreat. By these oscillations, gravel deposited just beyond the ice edge may have been laid down on till only recently deposited and may soon have been buried by till. The freshness of the gravel and till of these layers shows that neither was exposed long at the surface before the next higher member was deposited."

2. *The Gravel Hills.* "The kamelike gravel hills of the Iowan region are interpreted as gravel masses deposited in moulins or other openings in the Iowan ice sheet. On the melting of the ice these masses were left on or in the upper part of the drift sheet."

3. *The Valley Gravels.* "The valley gravels of the Iowan region and of the valleys of the Kansan region that carried Iowan drainage are interpreted as outwash from the Iowan ice chiefly during the withdrawal of the ice sheet. The valley gravels in those valleys of the Kansan region that did not receive Iowan drainage are believed to have been released from the Kansan till during an especially active period of erosion, owing to the lack of vegetation during the Iowan ice age, and to have accumulated farther down the valleys."

THE DISTRIBUTION, CHARACTERISTICS, AND OTHER FEATURES OF THE PLEISTOCENE GRAVELS OF IOWA

General Statement

The Pleistocene gravels of Iowa are of both glacial and interglacial origin. Each glacier which advanced into the state left gravel deposits. Theoretically, gravels were deposited in three general positions by the water from the melting glaciers: (1) in front of the advancing glacier which later overrode those within the area of till deposition, reincorporating some of the gravels into the glacial load and leaving the remainder of the gravels at the base of the till; (2) within the till sheet during the deposition of the till; (3) as outwash on the surface of the newly deposited drift sheet during the retreat of the glacier. During the interglacial intervals, gravels were deposited along the courses of streams which were dissecting the drift plain. These gravel deposits differ from those of glacial origin primarily in their relations to the till sheets.

Gravel deposits, either glacial or interglacial, may be destroyed by interglacial erosion or by the corrasion of a younger ice sheet. Valley gravels may be reworked by post-depositional streams which occupy the valleys.

The Gravels of the Grandian Series — The Nebraskan and Aftonian Stages

The Nebraskan was the oldest of the Pleistocene glaciers. Studies of the deposits left by this glacier show that it passed over all of Iowa including the northeastern part which for many years was thought to be driftless. Outcrops of Nebraskan gumbotil have been studied at many places within the state (figure 3), and in some parts of the state its surface and distribution can be mapped. The Nebraskan drift contains sand and gravel as irregular masses as well as outwash on its surface. Both of these will be described as Nebraskan gravel.

The Distribution of the Gravel of the Nebraskan Stage

The Nebraskan gravels are found chiefly in two areas, eastern Iowa and southwestern Iowa. The locations of the exposures studied are

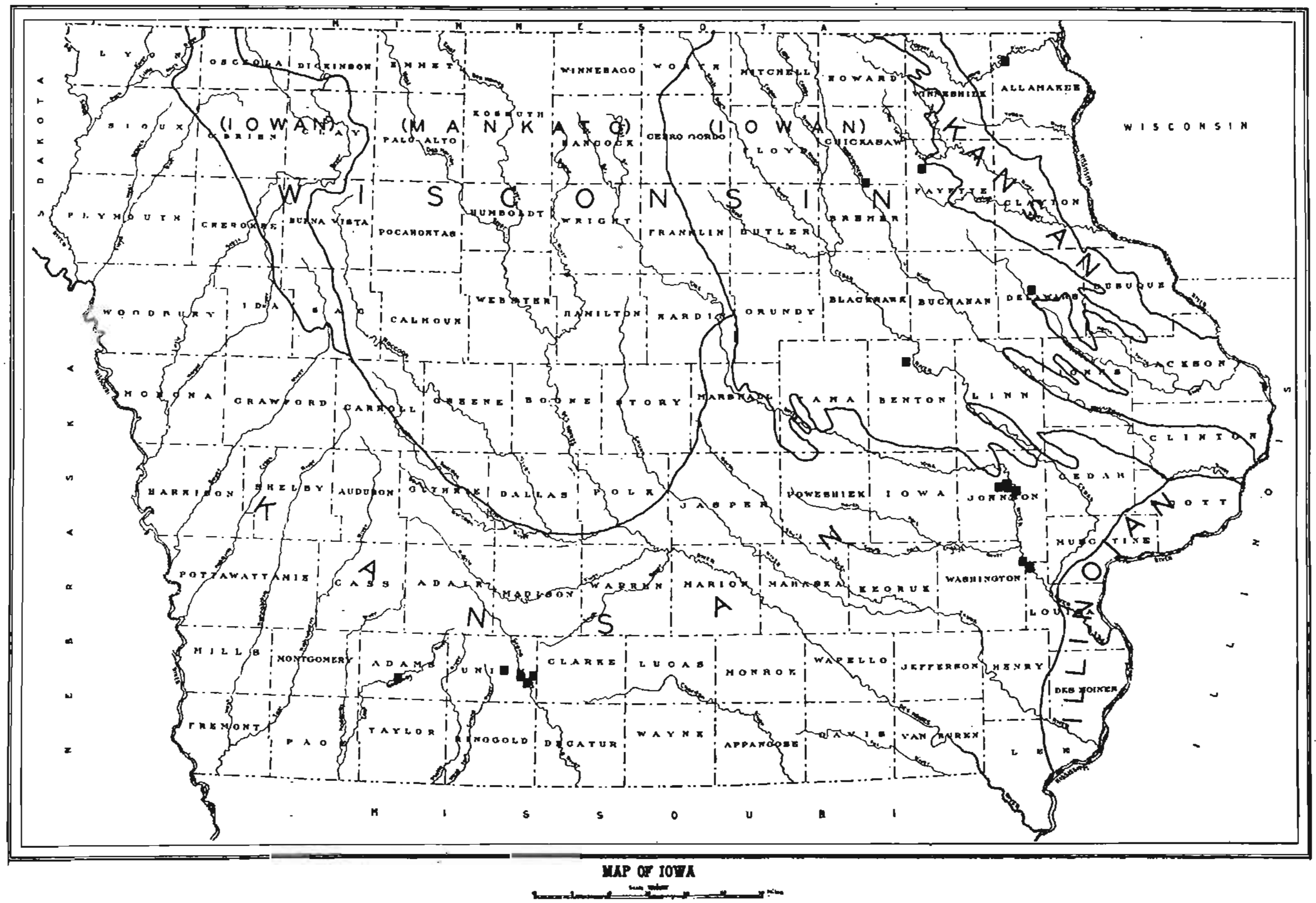


Fig. 7. — The squares show the locations of the Nebraskan gravel exposures in Iowa.

shown in figure 7. The limited number of exposures of Nebraskan gravel is due to the restricted area of exposed Nebraskan deposits. Throughout all of Iowa except a small portion of the northeastern part, covered only by loess, the Nebraskan deposits have been covered by one or more younger drifts. The Nebraskan deposits have not only been concealed by later deposition but much Nebraskan drift was removed by erosion, chiefly during the Aftonian interglacial interval. As a result of post-Nebraskan erosion which removed the younger overlying drift in some places good sections of Nebraskan drift have been made available for study.

The Characteristics of the Gravel of the Nebraskan Stage

General Characteristics:

The Nebraskan gravel occurs as pockets within the Nebraskan till and as outwash at the surface of the till. The gravel and the till have been subjected to weathering and have undergone comparable alterations. As soon as the drift was exposed after the retreat of the ice, chemical weathering began to act on the materials at and near the surface. This alteration continued over those wide areas where there was little, if any, erosion until the profile of figure 8 was developed. The alteration in the gravel, although comparable, was not to the same extent as that in the till, for within the more porous gravel the alteration extended to greater depths, unchecked by the formation of an impervious layer of gumbotil at the surface.

During the time that the till was being altered to the profile of figure 8, the gravels within the zone of weathering were being oxidized and leached. The oxidized iron compounds coated the grains, coloring the gravel to shades ranging from buff (15'i, Ochraceous-Tawny) [25] to highly ferruginous reddish-brown (11'k, Hazel), the average color being more nearly the reddish-brown extreme. The iron oxide coating the grains also acts as a cement which binds the gravel together into a firm mass which will stand in a vertical exposure. After the weathered gravel has been exposed to the atmosphere for a short time the cement hardens, beginning at the surface, and forms a friable conglomerate layer several inches thick. In the gravel deposits at and near the gumbotil horizon the oxidation extends to greater depths than in the more compact till. However, in the gravel deposits

25 The numerical and descriptive color terms within the parentheses are those used by Ridgeway. Ridgeway, Robert, Color Standards and Nomenclature, 1912.

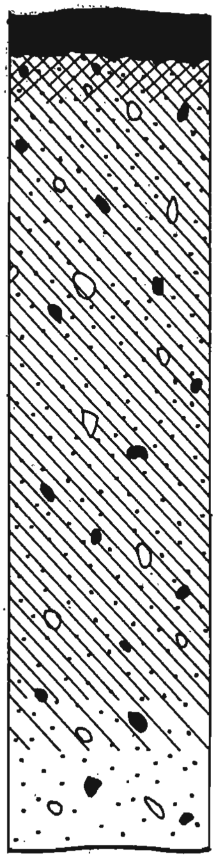


FIG. 8. — Diagram showing profile of weathered Nebraskan till.

located lower down in the Nebraskan till profile, in the oxidized and unleached and the unoxidized and unleached zones, the oxidation is much less to almost absent.

The processes of chemical weathering have leached also the more soluble substances such as carbonates from the upper portion of the drift and its associated gravel. However, the gravel masses enclosed in the lower unleached part of the Nebraskan profile contain their original rocks, many of which are calcareous, also lime concretions, molluscan shells, and numerous fossils of different species of vertebrates.

The deposits are generally well stratified in beds having a general horizontal position, but lenses, pockets, and cross-bedding are very

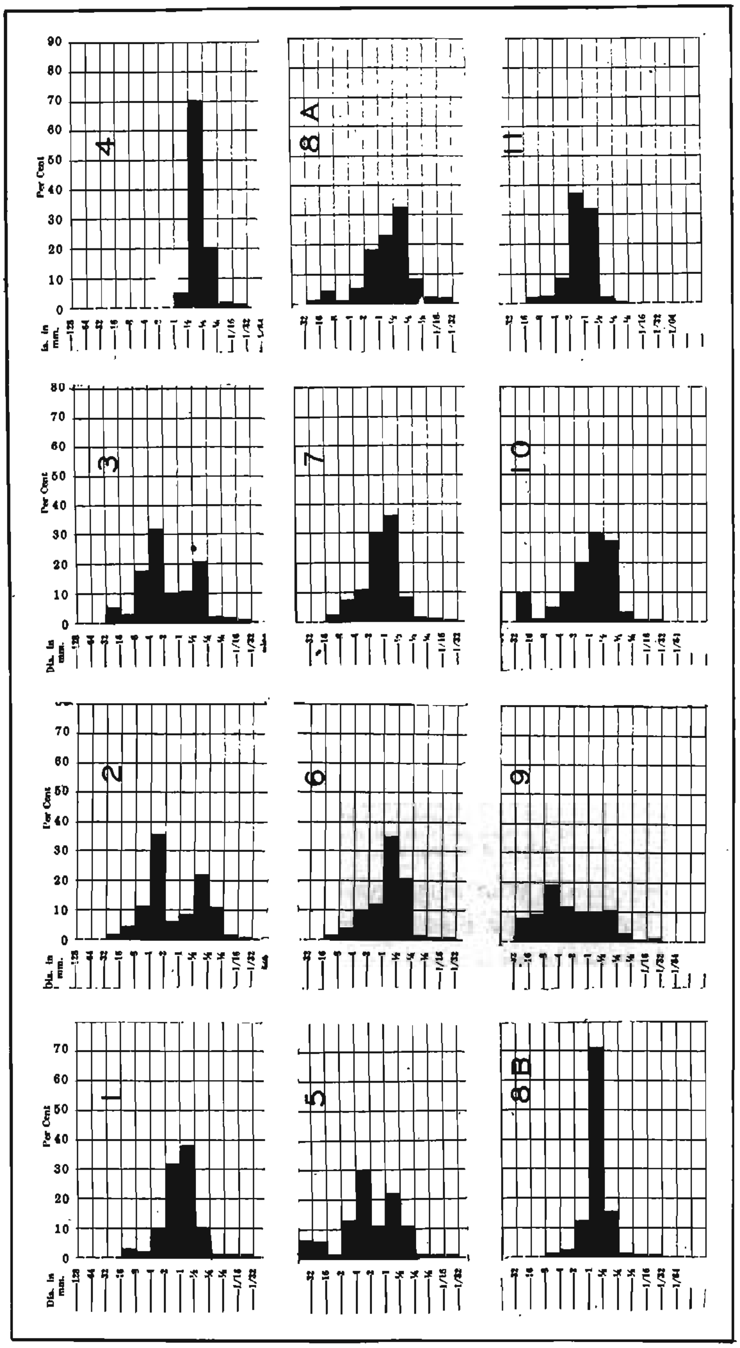


FIG. 9. — Graphs showing mechanical analyses of the Nebraskan gravel.

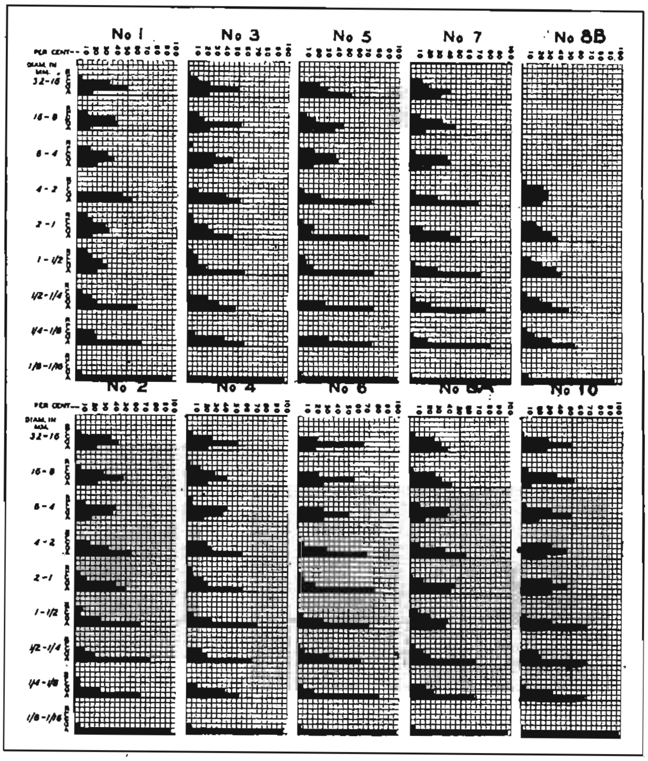


FIG. 10. — Graphs showing shape analyses of size grades between 1/16 and 32 millimeters in diameter. The numbers of these analyses correspond to the numbers of the mechanical analyses of figure 9. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

common. However, the poor sorting and the high degree of alteration give some of the deposits a massive, poorly stratified appearance.

The gravel shows a wide size range both within single exposures and in different exposures. Most of the gravel is below one centimeter in diameter, although there are beds which consist almost entirely of pebbles between one and three centimeters in diameter. Still larger than the pebbles are cobbles and boulders distributed throughout the finer material and bearing no relationship to the stratification. These boulders have been observed to have a maximum diameter of about 75 centimeters. The percentage of each of the different size grades, determined by mechanical analyses, is shown graphically in figure 9 for the exposures later described. The percentage of rounding, as defined and named by Tester [25a] of each size grade between 1/16 and

[25a] Tester, A. C., The measurement of the shapes of rock particles: Jour. Sed. Petrol., Vol. 1, pp. 3-11, 1931.

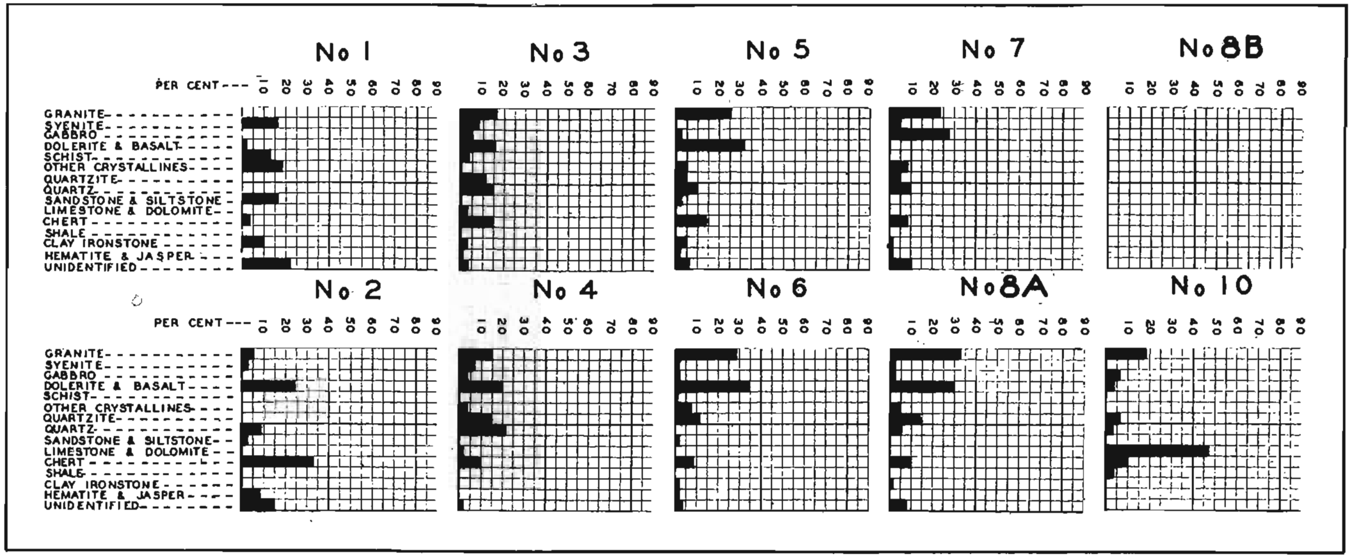


Fig. 11. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond to the numbers of the mechanical and shape analyses of figures 9 and 10.

32 millimeters in diameter is given in figure 10. The lithology, determined by an analysis of pebbles between 16 and 32 millimeters in diameter, is shown in figure 11.

There is a wide range in the thickness of the deposits of Nebraskan gravel. At some locations they are a bed only a few inches thick while at others they are as much as 30 feet thick.

Characteristics of the Nebraskan Gravel of Eastern Iowa

The exposures of Nebraskan gravel within Iowa, as shown in figure 7, include those which have been called Aftonian in previous reports; but as stated by Kay and Apfel,[26] the name Aftonian refers to the time of alteration of the gravel rather than to the time of deposition.

One of the best-known places within the state of Iowa to study these profoundly altered deposits is in the vicinity of Iowa City, in Johnson county. Here within a limited area, shown in figure 12, ten Nebraskan exposures can be definitely correlated and half of them contain gravel.

The weathered gravel is well exposed in the east central part of section 9, West Lucas township (T. 79 N., R. 6 W.), Johnson county, along both sides of the interurban railway cut just west of the Iowa river at Iowa City, at G in figure 12. The gravel is exposed also in small masses in the quarry one block south, and again in a road cut two blocks south of the interurban cut. This same type of gravel has been reported at the same elevation along the east side of the valley in the basement of the Women's Gymnasium. These gravel deposits are at an elevation of about 670 feet above sea level, about 30 feet below the upland and an equal amount above the Iowa river, in a region of loess mantled erosional topography.

Along the north side of the interurban railway cut just west of the Iowa river at Iowa City, the following section is exposed:

	Feet
4. Loess, buff colored, minimum leaching 8 feet, contains fossils (Peorian)	25
3. Loesslike material, light reddish-brown, all leached (Loveland)	2
2. Gravel, highly oxidized and leached (Nebraskan)	8
1. Till, dark gray, unoxidized and unleachëd (Nebraskan)	1

The gravel is colored reddish-brown (11'k, Hazel) by the iron oxide which coats the grains and cements them into a compact mass

26 Kay, G. F., and Apfel, E. T., The Pre-Illinoian Pleistocene Geology of Iowa: Iowa Geol. Survey, Vol. XXXIV, p. 182, 1929.

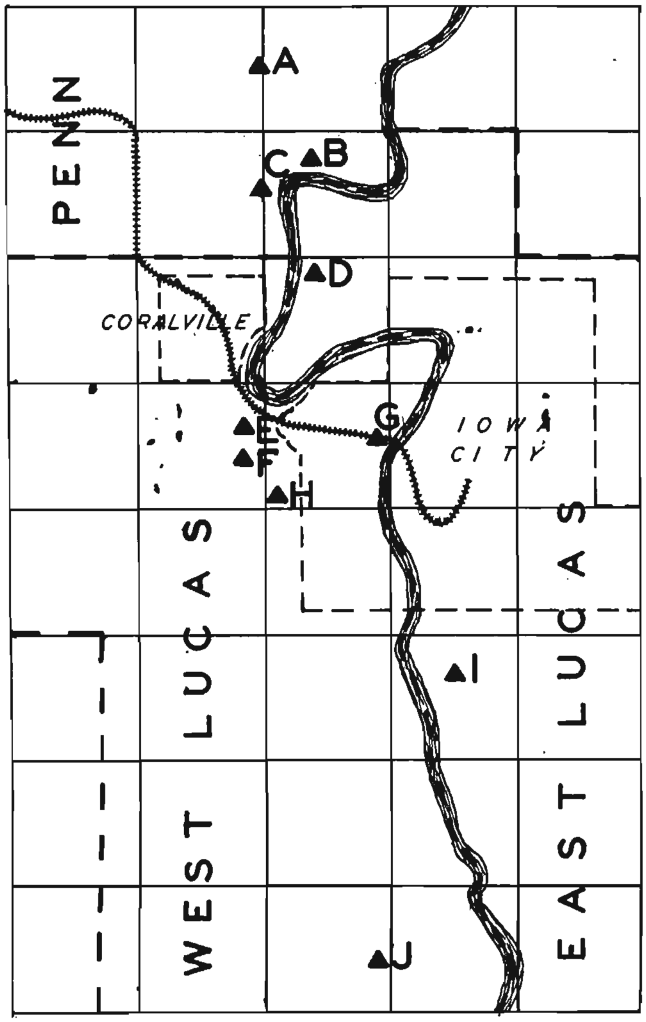


FIG. 12. — Map showing the locations of the Nebraskan exposures in Johnson county.

which case-hardens on exposure to the atmosphere so that it maintains a vertical face, and requires the use of a pick to obtain a sample. The entire section of gravel has been leached of its carbonates and many of the pebbles are extremely weathered, as shown in figure 13. Some of the granites and other igneous rocks fall to pieces during collection and others are cracked so that they can be broken between the fingers. The gravel is well sorted and stratified in thin layers which are separated in places by a thin bed of finer sand or a bed of small pebbles

FIG. 13. — Weathered pebbles from the Nebraskan gravel.

or granules, but in no place was cross-bedding observed. The gravel is very uniform in clastic texture; nothing coarser than three centimeters in diameter was observed and anything larger than one centimeter in diameter is only in the thin beds which are interstratified with the finer material. A mechanical analysis of a sample of average material is given in No. 4 of figure 9. The shape of the various size grades between 1/16 and 32 millimeters in diameter is shown in No. 4 of figure 10, and the rock content, determined by an analysis of pebbles between 16 and 32 millimeters in diameter, is shown in No. 4 of figure 11.

Another exposure of Nebraskan gravel is in the southwest quarter of section 22, East Lucas township (T. 79 N., R. 6 W.), Johnson county, at I in figure 12, along the east side of the Iowa river valley, one mile south of Iowa City. The best exposure is in a gravel pit, but the gravel is exposed also in a ditch a short distance to the north and in a gully east of the pit. All of these exposures are at the same elevation, 650 feet above sea level.

In the best exposure there is 15 feet of gravel, highly oxidized and leached of its carbonates. The gravel is overlain by 6 feet of Peorian loess and there is some evidence of a thin band of Loveland loess separating them.

In general this exposure is similar to that of the interurban cut. The beds are highly oxidized to a dark reddish-brown (11'i, Hazel), the iron oxide forming a mass more compact than that in the interurban cut exposure, since material has been recently removed and very little case-hardening has developed. A comparison of the analysis No. 3 and No. 4 of figure 9 shows that this exposure has a greater size range than No. 4. The exposure contains a greater percentage of material between 4 and 16 millimeters in diameter and also six large boulders between 25 and 40 centimeters in diameter within the gravel and unrelated to the stratification. A shape analysis is shown in No. 3 of figure 10, and a rock analysis in No. 3 of figure 11. The gravel is well stratified, the lower half being in a horizontal position, truncating the upper half, which dips at an angle of about 45 degrees.

Another interesting exposure of Nebraskan gravel is in the southeast quarter of the northeast quarter of section 8, West Lucas township (T. 79 N., R. 6 W.), Johnson county, in a ravine along the south side of the Finkbine golf course, at F in figure 12.

This gravel is at an elevation of 665 feet above sea level in a region of loess mantled erosional topography. The upper surface, which is at the Nebraskan gumbotil horizon, is about half way between the valley bottom and the divide. Here the section is as follows:

	Feet
4. Loess, buff, leached (Peorian)	7
3. Gumbotil, gray, containing more gravel with increase in depth until it grades into gravel (Nebraskan)	5
2. Gravel, well stratified, slightly oxidized, leached (Nebraskan)	12
1. Gravel, well stratified, slightly oxidized, unleached (Nebraskan)	3

The gravel of this exposure differs from that of the exposures previously described chiefly in the limited amount of alteration which it has undergone. The iron oxide colors it to a light-buff (15'1, Hazel), but is not sufficient to form a cement. Thus the uncemented beds slump readily and conceal the lower portions of the cut. Disintegration has not been as effective as in the other exposures described, and leaching has removed the carbonates below the gravelly gumbotil to a depth of only 12 feet, below which the gravel effervesces freely from both primary and secondary calcium carbonate. Since the other exposures of Nebraskan gravel show greater alteration, it seems probable that the impervious layer of overlying gumbotil has checked the descent of ground water, and thus has lessened the amount of chemical weathering. The gravel shows good horizontal stratification with some cross-bedding. The size, shape, and rock analysis are shown in No. 2 of figures 9, 10, and 11, respectively.

There is another exposure of Nebraskan gravel on the Finkbine golf course at E in figure 12, in the northeast quarter of section 8, West Lucas township (T. 79 N., R. 6 W.), Johnson county.

This exposure it at the same elevation as the exposure described above, 665 feet above sea level. The material resembles that which has been previously described, and the analysis of the size, shape, and rock content are shown in No. 1 of figures 9, 10, and 11, respectively. The gravel exposed is 8 feet thick, leached and highly oxidized. It is overlain by Peorian loess.

During excavation for the new football stadium, at H in figure 12, the Nebraskan gumbotil surface was exposed in several places. The relationship between the till and gravel was similar to that of other exposures. At some places the gumbotil occupied the surface, at others the gravel, and between there was generally a narrow gradation zone from one to the other. This exposure shows the relation of the till to the gravel on a horizontal surface. The elevation of the Nebraskan surface at this location is 665 feet above sea level. This section has been fully described by Kay and Apfel.[27]

A small pocket of gravel in the Nebraskan till occurs at Lovers Leap, D in figure 12. Slumping and vegetation have made a study of the exposure impossible.

In Delaware county, Nebraskan gravel is exposed 1 1/4 miles north of Manchester, in the northeast quarter of section 17, Delaware township (T. 85 N., R. 5 W.), in the valley of Honey Creek.

This is a region of gently rolling Iowan drift topography and the gravel occurs 15 feet above the level of Honey Creek, at an elevation of 985 feet above sea level, the same elevation as the Nebraskan gumbotil exposed in a road cut one-eighth mile farther north.

The gravel is colored to a dark reddish-brown (11'i, Cinnamon-Rufous) by the extreme oxidation of the iron compounds, which coat the grains and cement them into a compact mass which hardens on exposure to the atmosphere and maintains a vertical face. Leaching has removed the carbonates from the entire 15 feet of gravel, and many pebbles are extremely weathered. The exposure shows a wide size range in the material; most of the gravel is below 2 centimeters in diameter, although there are thin beds which consist almost entirely of pebbles ranging between 2 and 10 centimeters in diameter. Pebbles, cobbles, and boulders are distributed throughout the mass with no relation to the stratification. A mechanical analysis of a sample of average material is shown in No. 5 of figure 9. The material is well stratified in a general horizontal bed. Although no cross-bedding is present, the absence may be due to the extreme oxidation and leaching which tends to obliterate the finer structure.

27 Kay, G. F., and Apfel, E. T., The Pre-Illinoian Pleistocene Geology of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 153-154, 1929.

The percentage of rounding of the grains in the different size grades is shown in No. 5 of figure 10, and the rock content, determined from a pebble count, is shown in No. 5 of figure 11. Stratigraphically, the gravel lies above limestone and below leached till.

Another exposure of Nebraskan gravel is in a pit in the southeast quarter of the southwest quarter of section 8, Windsor township (T. 94 N., R. 9 W.), Fayette county, about 6 miles west of West Union. The exposure occurs within the Iowan drift area, in which there is a relief of more than 100 feet, the upper one-third the result of irregular distribution of the Iowan drift and loess. The Nebraskan gravel deposit is only a few feet above the valley bottoms, at an elevation of 1050 feet above sea level.

This gravel is very much like that previously described. It is colored to a dark reddish-brown (11'i, Cinnamon-Rufous) and cemented into a compact mass by the iron oxide. The carbonates have been leached from the entire 10 feet of gravel exposed, and weathering has disrupted many of the rocks. Size, shape, and rock analysis are given in No. 7 of figures 9, 10, and 11. The overburden consists of Iowan till about 30 inches thick. No contact at the base of the gravel was exposed.

In Chickasaw county the Nebraskan gravel is exposed in the northeast quarter of the southwest quarter of section 31, Dresdon township (T. 94 N., R. 12 W.), along the east side of primary number 59 and of the valley of the Wapsipinicon river.

The gravel occurs only a few feet above the valley flat of the river, at an elevation of 1045 feet above sea level, in a region of gently rolling Iowan drift topography.

The gravel is highly colored to the usual reddish-brown (11'k, Hazel) by the extreme oxidation, which also cements the grains into a compact mass. Leaching has removed the carbonates from all of the 12-foot exposure. Many of the rocks such as granite are weathered so that they crumble readily by slight pressure, and others are cracked so that they can be broken between the fingers. The deposit consists of two members, both the same age, separated by a pebble band which consists of a layer of pebbles. The upper 4-foot member consists entirely of sand, well stratified in horizontal beds. The lower member resembles more nearly the other exposures of Nebraskan gravel. It is 8 feet thick, well stratified, and contains a small amount of cross-bedding. Aside from the 20 boulders which lie in the bottom of the pit there is practically nothing coarser than 3 centimeters in diameter, and the pebbles are all within the pebble band and the lower member of the deposit. A size analysis of the average material of each member is given in No. 8 of figure 9; (A) represents the lower member and (B) the upper member. The shape of each size grade of the upper and lower beds is shown in figure 10, number 8A the lower bed, and 8B the upper bed. The shape analyses of the size grades coarser than 4 millimeters in diameter in 8B are missing, since there was no material of these size grades in that bed. A rock analysis, determined by a pebble count, is shown in No. 8 of figure 11. This analysis is for the lower member only.

Weathered Nebraskan gravels are exposed in Washington and Louisa counties at locations about 2 miles apart. Within this area there are also several exposures of Nebraskan till by which Schoewe [28] has determined the elevation of the old Nebraskan gumbotil plain to be between 620 and 640 feet above sea level. The first of these two exposures of gravel is located in the extreme southeast quarter of section 36, Iowa township (T. 77 N., R. 6 W.), Washington county. The second exposure is in the northwest quarter of the southwest quarter of section 8, Union township (T. 76 N., R. 5 W.), Louisa county. Neither of the exposures is more than one-half mile from the Iowa river and both are only a few feet above the level of the stream.

Schoewe [29] states that the two gravel sections are very much alike, differing only in a few minor details. He describes the section in Washington county as follows:

	Feet
3. Light ash-colored drift	10
2. Leached and oxidized sands and gravels	20
1. Dark bluish calcareous drift; compact, unoxidized, and containing small pebbles	4

"Towards the base of the sand and gravel deposit, the gravels predominate. The textural range of the gravels is rather high, the pebbles varying from small fragments the size of a pea to pieces several inches in diameter, the finer material, however, being in excess. The gravels are cross-bedded.

"The sands are highly oxidized and have a brownish color, are fairly fine and have a low textural range. In structure they are highly contorted,

28 Schoewe, W. H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 49-222, 1924.

29 Schoewe, W. H., Interpretation of Certain Leached Gravel Deposits in Louisa and Washington Counties, Iowa: Proc. Iowa Acad. Sci., Vol. XXVI, pp. 393-398, 1920.

dip at high angles, are cross-bedded and at places, especially in the middle of the deposit, are more or less horizontal. A lens and pocket structure is conspicuous throughout the exposure in which occasionally leached mud or clay balls are found.

"Although but ten feet of the ash-colored drift is exposed, the slope of the hill is covered by drift to a height from forty to fifty feet above the section. The exposed portion of the till contains limestone pebbles and is filled with many concretions. Higher up the slope of the hill, the drift is leached. The entire outcrop is from 150 to 250 feet long.

"The other section differs but little from the one just described, except that it contains less gravel and no drift is exposed beneath the sands. However, it contains near the base several thin leached layers of till from one to two feet thick. Here and there, a well weathered limestone pebble occurs in it, nor are lime concretions entirely wanting.

"On the whole, the stratification of the sands and gravels of the exposure in Louisa county is more horizontal than that of the one in Washington county. Barometric readings show that the two sections lie approximately at the same elevation, namely, from 620 to 630 feet above sea level. The length of the second outcrop is the same as that of the first and the exposure is forty feet high."

A mechanical analysis of an average of the material from the exposure described above, in Washington county, shows that the percentages of the different size grades are very similar to those in the exposure at F in figure 12, on the south side of the Finkbine golf course (No. 2 of figure 9). Like the other exposures of extremely weathered gravel there is considerable rounding of the grains by solution; also many of the rocks such as granites are so weathered that they crumble easily, and others when broken show a weathered band at the surface. All of the limestones and dolomites have been removed by solution.

Gravels in the Afton Junction-Thayer Region

Until the importance of Nebraskan gumbotil as an Aftonian horizon marker separating the Nebraskan till from the Kansan till was recognized a few years ago, other materials were emphasized as bases for separating the Nebraskan till from Kansan till. Chief among these criteria were weathered sands and gravels and peats lying between the two oldest tills. Type sections of the two oldest tills separated by gravel are in the region of Afton Junction and Thayer in Union county in southwestern Iowa, the location of which is shown in figure 8. In fact, the Aftonian gravels in this part of the state are so well known by students of Pleistocene geology that one hesitates to state that a restudy of these famous exposures and other exposures in the same region has revealed evidence which seems to justify further discussion of the origin and relationships of these gravels, and to warrant questioning some of the former interpretations.

From the time the gravel pits of this area were opened more than 35 years ago and their interesting characteristics revealed, they have been visited by many glacial geologists of America and of Europe. Some persons have come merely to see the type sections of the two oldest tills, now known as the Nebraskan and the Kansan, separated by the gravels which for many years have been called the Aftonian interglacial gravels; others have come to study carefully the characteristics of the tills and gravels and their inter-relationships. The most important contributions dealing with these gravels and associated deposits have been made by Dr. T. C. Chamberlin, Dr. H. F. Bain, and Dr. Samuel Calvin.

The chief gravels are exposed in three gravel pits in Jones township and a gravel pit in Union township, Union county, figure 14. One

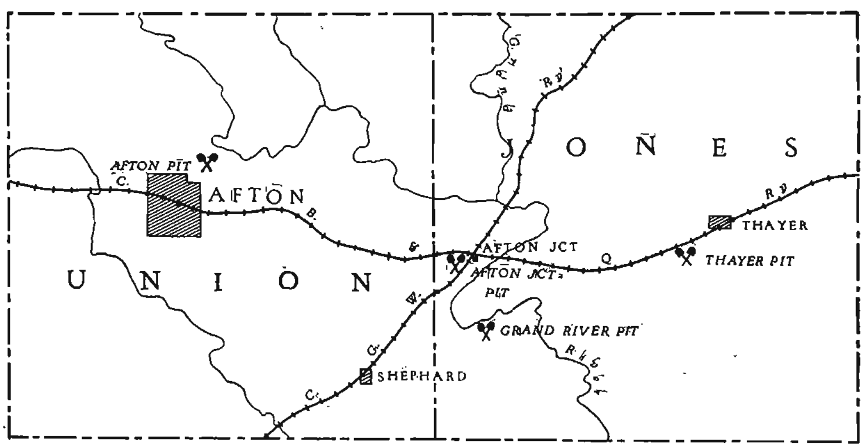


FIG. 14. — Map showing locations of Nebraskan gravel exposures of the Afton Junction-Thayer region in Union county.

pit, known as the Afton Junction pit, is about 200 yards west and somewhat south of Afton Junction station on the Chicago Great Western railway, and of the Great Western Crossing on the Chicago, Burlington and Quincy railway; a second pit, called the Grand River pit, is on the south bank of Grand River more than a mile southeast of Afton Junction station; the third pit in Jones township, the Thayer pit, is about three-fourths mile southwest of Thayer station. All of these pits have been abandoned for more than 30 years. Northeast of Afton, Union township, a pit was opened only recently and from it gravels are still being taken. This will be called the Afton pit.

In an earlier part of this report there is a discussion of these most interesting gravels, including the evidence upon which they were differently interpreted by different authors. Here it is sufficient to say that Chamberlin interpreted the gravels to be kame-like deposits on the surface of the Nebraskan drift and related in age to this drift. Bain referred to evidence of lateral transition from gravels into boulder clay and suggested the possible contemporaneity of the gravels with the Kansan till. Calvin, in 1905, interpreted these gravels to be deposits made by torrential floods during the retreating stages of the pre-Kansan ice. Later, in 1908, as a result of studies by himself and Shimek of gravels and their included fossil faunas in western Iowa, Calvin suggested a modification of his former view regarding the origin of the Aftonian gravels in the Afton Junction-Thayer region. He expressed the judgement that the most satisfactory interpretation of the gravels is that they are strictly interglacial in age, having been deposited during the progress of the Aftonian interval, neither at its beginning nor at its end.

Recent extensive studies of these type sections of gravels and tills in Union county and studies also of the relations of gravels to tills and gumbotils in several other counties in southwestern Iowa have shown clearly that these gravels were not deposited within the Aftonian interglacial epoch to constitute a distinct stratigraphic horizon separating the Nebraskan till from the Kansan till. Although some of the gravels do lie on the surface of the Nebraskan till and are related in age to this till the gravels as a whole are not limited to the surface of the Nebraskan till. There are lenses and irregularly shaped masses of gravels in the Nebraskan till and these gravels are comtemporaneous in age with the Nebraskan till. Moreover, there are many inclusions of the Nebraskan gravels in the overlying Kansan till, and it is thought that some gravels in the Kansan till are contemporaneous in age with that deposit.

Three sections in the Afton Junction region show clearly the relationships of the Aftonian gravels to the Nebraskan till. The sections are located as follows:

1. In the Afton Junction pit in the northwest quarter of the southwest quarter of section 19, Jones township (T. 72 N., R. 28 W.), Union county. This pit is about 200 yards west and somewhat south of Afton Junction station on the Chicago Great Western railway, and of the Great Western crossing of the Chicago, Burlington and Quincy railway.

2. A road cut in the southwest quarter of section 7, Union township (T. 72 N., R. 29 W.), Union county.

3. In the Afton gravel pit in the northeast quarter of section 16, Union township (T. 72 N., R. 29 W.), Union county, northeast of Afton.

A section in the southwest corner of the old Afton Junction pit shows till and related materials. The section is about 200 yards south of a railroad cut in the base of which, many years ago, Aftonian gravels were exposed and were described by Calvin. With reference to the Aftonian gravels in this railroad cut it is worthy of note that Frank Leverett reports that more than 25 years ago he and Douglas Johnson found near the west end of the cut some carbonaceous material overlying the gravels and underlying 30 feet or more of Kansan till. The elevation of the surface of these gravels, it is well to emphasize here, is less than 10 feet lower than the top of the section in the Afton Junction pit. The elevation at the top of the section to be described is about 1120 feet above sea level. The section in the southwest corner of the Afton Junction pit is as follows:

	Feet
4. Loess, leached	11
3. Gumbotil, Nebraskan, compact, dark drab to chocolate color, reddish on dry surface, few siliceous pebbles, leached	6
2. Till, Nebraskan, gray to drab, leached, compact, grading below into less compact, more yellowish colored till and gravelly till	5
1. Gravelly till, oxidized, leached	3

Below the lowest part of the section there is considerable slump, but the chief gravel which was taken from this pit years ago was below the base of the above section.

Only about 50 yards to the east of this section there is a steep slope in the south part of the pit. Here the following section was taken. The top of the section is at the same elevation as the top of the section which has just been described:

	Feet
4. Loess, leached	10
3. Till and gravelly till, Nebraskan, the gravel highly oxidized, upper three feet very gravelly and chocolate-colored, leached	13
2. Till and gravelly till, Nebraskan, unleached, the till in part oxidized and in part unoxidized, many concretions	6
1. Gravel, Nebraskan, highly oxidized, many concretions, unleached, in places cemented; exposed	5

The leached and gravelly till in the upper part of this section is related closely to the gumbotil of the adjacent section and to the Aftonian gravel horizon in the railroad cut a short distance to the north. All are at the surface of the Nebraskan drift and are Nebraskan in age. The changes of the original Nebraskan till to gumbotil and of the sand and gravel to its present highly oxidized and leached condition took place during the Aftonian interglacial age and before the Kansan drift was deposited upon them. The chief gravels are at the surface of the Nebraskan till and in lenses and irregularly shaped masses in the Nebraskan till. In quantity the lenses and irregularly shaped enclosed masses of sand and gravel are far more extensive than the masses of sand and gravel at the surface of the Nebraskan till. Only those weathered sands and gravels which separate the Nebraskan till from the Kansan till can be used stratigraphically in differentiating these tills. It is interesting that the gumbotil and the leached gravel at the same elevation as the gumbotil are at approximately the same elevation as an exposure of Nebraskan gumbotil underlain by Nebraskan till and overlain by Kansan till in a road cut between sections 17 and 20, Jones township (T. 72 N., R. 28 W.), on the east slope of Grand River valley, about 1 1/2 miles northeast of Afton Junction. It is interesting also to note that the gravels in the Grand river and Thayer pits have approximately the same elevation as the gravel in the Afton Junction pit.

The second section showing clearly the relationships of the Aftonian gravel to the Nebraskan till is in a road cut about 3 1/2 miles west of Afton and about 1/2 mile southeast of Union County Poor Farm. It is in the southwest quarter of section 7, Union township (T. 72 N., R. 29 W.), Union county. The elevation of the base of this cut is about 1145 feet or 50 feet below the Kansan drift uplands. The cut is more than 100 yards long and is about 18 feet deep in its deepest part. The lower part is in Nebraskan gumbotil and the upper part is in loess. To the south of the road-cut and at a lower level is a stream-cut bluff exposing oxidized drift and gravelly drift. From the top of the road cut down to the level of the stream the section is as follows:

	Feet
4. Loess, yellowish to brownish in color, leached	8
3. Gumbotil, Nebraskan, gray color, few siliceous pebbles, leached	7
2. Gravel and sand, oxidized and leached	10
1. Till, and gravelly, Nebraskan, oxidized and unleached	5

A short distance to the east is a similar section, but here some of the unleached till in the lower part is unoxidized and the gumbotil zone has in it gravelly leached till.

In these sections the sand and gravel are pockets in the Nebraskan till and are of the same age as the till. During the time that the surface till was becoming gumbotil the sand and gravel intimately associated with it underwent extensive oxidation and leaching and became the "Aftonian gravels."

The third section which is to be described and which shows the relation of the Aftonian gravels to Nebraskan till is in the Afton gravel pit in the northeast quarter of section 16, Union township (T. 72 N., R. 29 W.), Union county, northeast of Afton. This pit was opened recently to secure road-making material and is still being used. The pit is at the end of a spur which extends into the flood-plain of Three Mile Creek. This spur has a gentle slope and the gravel is close to the surface. Above the gravel is about 3 feet of oxidized and leached till. The gravel in the deepest part of the pit is between 20 and 25 feet thick. The section exposed is as follows:

	Feet	Inches
9. Till, oxidized and leached	3	
8. Gravel, colored brown (15'i) by iron oxide, leached to a depth of about 18 inches, below which it is highly calcareous, good stratification, within which are cross-bedding, lens and pocket structures. Average thickness	5	
7. Silt, gray (17"b), unleached, well stratified	1	2
6. Silt, gray (17"b), unleached well stratified	1	4
5. Silt, buff like that of No. 7; contact with the underlying gravel is horizontal		10
4. Gravel, stratified in horizontal beds about one-half inch thick, an alternation of oxidized and unoxidized beds	2	
3. Gravel like that above, No. 4, but all dipping at a high angle toward the southeast; contains coarser material, some as large as three centimeters in diameter. Exposed	5	
2. Slumped material which conceals gravel	10	
1. Gravel like that of No. 3	3	

There is very little material in the pit larger than 2 centimeters in diameter except a few cobbles and boulders, the largest having an average diameter of about 35 centimeters. A few clay-balls are found within the coarser gravel. The clastic texture of a sample of average material from the gravel zones is given in No. 9 of figure 10. The percentage of rounding is shown in No. 9 of figure 11. The lithology, of pebbles between 16 and 32 millimeters in diameter, is shown in No. 9 of figure 12. The elevation at the top of the gravel is about 1130 feet above sea level. About one mile north of the gravel pit in the northwest quarter of section 10, Union township (T. 72 N., R. 29 W.), is an exposure of Nebraskan gumbotil underlain by Nebraskan till and overlain by Kansan till. The elevation of this Nebraskan gumbotil is about 1170 feet above sea level. A similar Nebraskan gumbotil outcrops about one mile south of Afton, also at an elevation of about 1170 feet. This evidence indicates that before erosion of the Nebraskan gumbotil plain began in this area the elevation of the gumbotil plain was about 1170 feet above sea level. This is 40 feet higher than the elevation of the gravel and on this evidence the gravel is interpreted to be part of the Nebraskan drift. In no sense is the gravel Aftonian as previously interpreted.

By way of summary, it may be stated that a study of the relationships of the gravel to tills in the Afton Junction region indicates that most of the gravel deposits of Union county which have been thought by some geologists to have been deposited during the Aftonian interglacial stage and to constitute a distinct stratigraphic horizon separating the Nebraskan and Kansan tills are not of this origin or age. Rather, the chief sand and gravel deposits are lenses and irregularly shaped masses of gravel in the Nebraskan till and contemporaneous in age with the Nebraskan till. They are not of Aftonian age but of Nebraskan age. They lie largely beneath the level of the Nebraskan gumbotil. However, in a few places, as for example in the Afton Junction pit, the Nebraskan gravel, as well as the Nebraskan till, were at the surface of the Nebraskan drift plain during the Aftonian interglacial interval. The surface Nebraskan till became weathered to Nebraskan gumbotil and the surface Nebraskan gravel became weathered to highly oxidized and leached gravel. Later, both oxidized and leached gravel and Nebraskan gumbotil were picked up by the Kansan ice and became inclusions in the Kansan till. Since the Nebraskan gravel which was weathered at the surface and which now separates the Nebraskan till below from the Kansan till above was altered during the Aftonian interglacial age, it may be thought proper to continue to call such deposits "Aftonian gravels," but it is here suggested that the name "Aftonian gravels" be no longer used for the sand and gravel which are of Nebraskan age but which were changed in Aftonian time, but that they be called weathered Nebraskan gravel just as Nebraskan gumbotil is the name given to weathered Nebraskan till, the weathering having taken place in Aftonian time. The weathered Nebraskan gravels do in places separate the Nebraskan till from Kansan till, and hence constitute an Aftonian stratigraphic horizon. But gumbotil, peat, and related materials, rather than gravel, are the most widespread evidence of Aftonian interglacial time.

Other Gravels in Western Iowa

Not only in the Afton Junction-Thayer region but farther north in Western Iowa, gravel and sand have been interpreted to have been deposited in Aftonian interglacial time, and thus to constitute a stratigraphic horizon separating the Nebraskan till from the Kansan till. In recent years the senior author has restudied this area, particularly Pottawattamie, Harrison, and Monona counties and the adjoining counties on the east. The chief purpose of the investigation was to determine whether a restudy of the tills, gravel, and related deposits of the area would permit, in the light of our most recent knowledge of the Pleistocene of southern, southwestern, and northwestern Iowa, a more satisfactory interpretation of the relationships and origins of these glacial materials than was possible when previous studies were made. Considerable additional field work will be necessary before final conclusions can be reached, but thus far the evidence warrants the following tentative statements:

1. The oldest known tills, the Nebraskan and the Kansan, separated in many places by Nebraskan gumbotil of Aftonian age, have been traced as far west as the western parts of Crawford and Shelby counties, less than twenty-five miles from the Missouri river, the western boundary of Iowa. The evidence in hand indicates clearly that both of these old tills formerly extended to the Missouri river and beyond into the state of Nebraska. If it were not for the thick deposits of loess overlying the tills in this region no doubt many additional good sections of them could be seen.

2. In western Iowa it has not been possible to distinguish the Nebraskan till from the Kansan till by differences in color, texture, lithologic composition, or degree of weathering. Only when it is possible to establish the relationship of an outcrop of till and associated gravel to gumbotil or other interglacial material the age of which is known can the definite age of the till and gravel be determined. When the till is overlain by Nebraskan gumbotil or can be shown to lie lower topographically than nearby remnants of the eroded Nebraskan gumbotil plain, then the till generally may be interpreted as being Nebraskan till. If, however, an outcrop of till is overlain by Kansan gumbotil, or if the till has the proper relation topograph-

ically to remnants of the eroded Kansan gumbotil plain, the till may be interpreted as being Kansan till.

3. The sands and gravels of western Iowa have been described by Shimek and Calvin as being Aftonian interglacial deposits separating the Nebraskan till from the Kansan till and related in origin neither to deposits made during the closing stages of the Nebraskan glacial epoch nor to those made during the Kansan glacial epoch. These sand and gravel deposits are thought by the present writers, however, not to represent a distinctive stratigraphic horizon separating the Nebraskan till from the Kansan till, but instead to be lenses and irregularly shaped masses of gravel and sand within a single till, or in two tills or between two tills and to be of no value as evidence for differentiating the two tills. The gravel and sand deposits are unleached and appear to be contemporaneous in age with the tills with which they are associated.

4. Many mammalian fossils have been found in the sand and gravel associated with the tills of western Iowa. Calvin and Shimek believed that these remains were of animals which were living during the time of gravel deposition,which they interpreted as Aftonian and interglacial. But if the sand and gravel deposits are lenses and irregularly shaped pockets related in age to the till with which they are associated, then a somewhat different interpretation of the age of the mammals becomes necessary. At the present time it is impossible to state whether these deposits in which the mammalian remains have been found are associated with Nebraskan till or with Kansan till, since, as stated above, it has not been possible thus far to differentiate Nebraskan till from Kansan till except where the relationships of the till to gumbotil — the age of which is known — have been established. If the gravel deposits in which the mammalian remains have been found should prove to be lenses and pockets in Nebraskan till then the evidence would suggest that the animals are Nebraskan in age. It would be reasonable to assume that the animals were living in front of the Nebraskan ice sheet, which was sometimes advancing and somtimes retreating and out from which sand and gravel were being carried. Remains of mammals became imbedded in the sand and gravel, which later were overridden by or became incorporated in the onward-moving Nebraskan till. If, on the other hand, the sand and gravel containing the mammalian remains should prove to be lenses and pockets in Kansan till, then the suggested interpretation would be that the mammals were living on the Aftonian surface during the advance of the Kansan ice sheet, out from which sand and gravel were being carried. After remains of mammals became imbedded in these sand and gravel deposits, the Kansan ice sheet, which was sometimes advancing and sometimes retreating, incorporated in the Kansan till these masses of sand and gravel in which the remains are found. If these con-

clusions are justified, then this mammalian fauna may not be a strictly interglacial fauna of Aftonian age. It is important to note, however, that the fauna is certainly early Pleistocene — that is, it was closely associated either with the advance of the Nebraskan ice or with the advance of the Kansan ice or with both, as a result of having persisted on the adjacent plains from Nebraskan through Aftonian to Kansan time.

Mammalian remains in the gravel do not of themselves determine whether the gravel is strictly interglacial in age or is of glacial origin, as vertebrate paleontologists are not in agreement regarding the climatic conditions under which mammals such as have been found in these deposits may live. Dr. O. P. Hay is of the opinion that the mammals, the remains of which have been found in gravel deposits of western Iowa, could not have lived in the immediate vicinity of an ice sheet, but must have lived under interglacial climatic conditions. On the other hand, W. D. Matthew believes that in determining the age of gravel and sand stratigraphic evidence can be more safely followed than fossil evidence. In a letter he stated:

"What actually seems to have happened in the Pleistocene was that glacial advances drove the boreal forms southward and compelled them to mingle temporarily with temperate faunas . . . When the retreat of the ice opened up northern territory again, the boreal types were the first to extend their range northward, and then or later retreated from the southern territory they had invaded."

Matthew offers no adverse criticism to the view taken in this paper that the sands and gravels of western Iowa containing the remains of mammals probably were contemporaneous in age with till with which they are apparently closely related in origin.

Relations of the Nebraskan Gravel.

The waters from the melting Nebraskan glacier deposited gravel at the base, within, and at the surface of the till. Following the retreat of the ice, during the early part of the Aftonian interglacial interval, the processes of weathering brought about many changes in those materials at and near the surface; the till was changed to a mature weathered profile (see figure 8). Comparable changes within the gravel are recorded in the leaching of the carbonates, the weathering of many of the igneous rocks such as granites and greenstones, and the high degree of oxidation of the iron compounds. After these changes had taken place and preceding the advance of the Kansan glacier, the old Nebraskan plain was thoroughly dissected by erosion. The gumbotil which had before covered the Nebraskan till surface now remained only on the divides to mark the horizon of that pre-existing surface. The erosion was checked by the advance of the Kansan glacier, which covered the Nebraskan glacial deposits with a thick layer of till, which during the Buchanan interval underwent changes similar to those the Nebraskan had undergone during the Aftonian interval. It is apparent that, undergoing similar histories, the deposits should likewise bear marked resemblances. The only unquestionable method of differentiating the tills and gravels is their relations to the gumbotil plain which at present occupies the uneroded divides of the old erosional surfaces. Since the only deposition on the Kansan in the areas studied is the thin Iowan till, Peorian loess, Loveland deposits and Illinoian till and these are thin and may occupy separate areas, the Kansan gumbotil horizon is near the tops of the present day hills. Likewise, the Nebraskan gumbotil horizon is about 50 feet (the thickness of the Kansan till) lower, generally only a few feet above the valley flats.

Throughout most of the state the correlation of the gravel is simplified to a certain extent because of its tendency to occur at or near the gumbotil horizon, which is relatively flat, dipping gently toward the south. However, in western Iowa the absence of gumbotil exposures and the indistinct relation to the drift sheets make impossible definite correlation by these methods.

Since the Nebraskan gravel deposits are exposed in widely separated areas, it will be necessary to discuss separately the relations of each area.

The type locality within Iowa in which to study the relations of the Nebraskan gravel to the other deposits is in Johnson county, near Iowa City. The relations of the ten exposures shown in figure 5 are given in the following table:

Location	*Elev. above S. L.*	*Material Exposed*
A. Section 29, Penn township	660	Peorian loess Nebraskan gumbotil
B. Quarry north of Coralville	660	Peorian loess Iowan terrace gravel Nebraskan gumbotil with gravel inclusions. Devonian limestone.
C. Between Coralville and Quarry	660	Peorian loess Kansan till Nebraskan gumbotil Nebraskan till Devonian limestone.

D. Lover's Leap	665	Nebraskan gravel Devonian limestone.
E. North side of Finkbine golf course	665	Peorian loess Nebraskan gravel
F. Finkbine golf course 500 yards south of E.	665	Peorian loess Nebraskan gumbotil Nebraskan gravel.
G. Interurban cut west of the Iowa river at Iowa City	670	Peorian loess Loveland loess Nebraskan gravel Fresh Nebraskan till.
H. New University Football stadium	665	Peorian loess Loveland loess Nebraskan gumbotil and Nebraskan gravel Nebraskan till.
I. South of Iowa City, section 22, East Lucas township	640	Peorian loess Nebraskan gravel Devonian limestone.
J. Indian Lookout south of Iowa City	660	Peorian loess Kansan gumbotil Kansan till Nebraskan gumbotil.

As shown by the elevations given in the preceding chart, the surface of the old Nebraskan gumbotil plain was approximately 660 feet above sea level with but little relief. The exposures of gravel are at about the same elevation as the gumbotil, the greatest difference in elevation being 25 feet. If the old Nebraskan plain were reconstructed, using the elevations of the ten locations of the Nebraskan exposures shown in figure 13, the maximum slope required would be 12 1/2 feet per mile or about one-third of one per cent grade.

Since the surface of the Nebraskan drift was a plain, it might be concluded, that the gravel deposits previously described belonged to the same deposit as the gumbotil, if one considered elevation alone; but more conclusive evidence is available. In the exposure F, along the south side of the Finkbine golf course, the gravel lies below and grades upward into a thin bed of Nebraskan gumbotil. In the base of the new University football stadium at H, there is a lateral gradation from the gravel through gravelly gumbotil into gumbotil. As previously stated, whether the surface of the drift be gravel or till, it was subjected to the same processes of weathering which would form comparable changes within them. In exposures such as G and I, in which the gravel occupies a surface position, they are entirely leached of their carbonates, a maximum depth of 16 feet being observed. But in exposure F, where the gravel was overlain by till which probably retarded the chemical action of the ground water, it is leached to a depth of only 12 feet and oxidation is slight. These contacts of the gravel with the gumbotil, both lateral and vertical, eliminate all possibilities of any time of deposition other than that of the deposition of the till.

That the till with which the gravel deposits are associated is Nebraskan and not Kansan is proven by the occurrence of a younger till above the Nebraskan gumbotil. At Indian Lookout, J, there are two gumbotils, the lower one, the Nebraskan, 660 feet above sea level, and the upper, the Kansan, 700 feet above sea level. North of Coralville, at C, the lower gumbotil, the Nebraskan, is overlain by a younger till, exposed for 25 feet, above which it is concealed by vegetation. Thus it may be concluded that the Kansan gumbotil plain was 40 feet higher than the Nebraskan gumbotil at J, and more than 25 feet higher at C.

If the gravel deposits which occur on the surface of the lower till were to be correlated with the younger till, it would necessitate postulating considerable relief on the Kansan gumbotil surface which was not the case, or a minimum leaching of the carbonates to a depth of 30 feet and a maximum of 80 feet. But these postulated depths of leaching are far greater than any observed.

The Nebraskan gravel deposits in Delaware county occur in the valley of Honey Creek at an elevation of 985 feet above sea level, at the same elevation as the Nebraskan gumbotil exposed along the west side of the road one-eighth mile north. Another exposure of Nebraskan gumbotil occurs in the same valley 3 1/2 miles farther north, at about the same height above the stream level as the first exposure of Nebraskan gumbotil and the Nebraskan gravel. If the surface of the Nebraskan gumbotil plain were reconstructed from these exposures it would have a gentle slope to the south almost equal to that of Honey Creek,

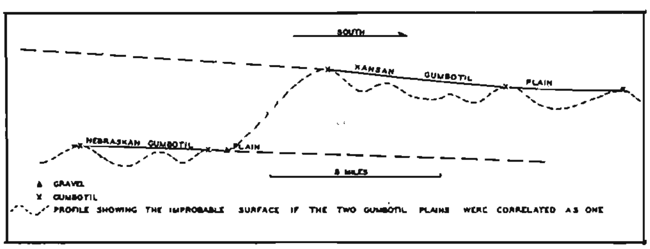


FIG. 15. — Diagrammatic profile showing the relation between the Nebraskan and Kansan gumbotil plains in Delaware county.

which is flowing at grade. Like the gravel, the gumbotil exposure farthest north lies upon the bedrock surface.

Differing in position from the Nebraskan gumbotil deposits previously described which occur in the valley north of Manchester, the Kansan gumbotil occurs on the divides south of Manchester. The relations of the two gumbotil surfaces are shown graphically in figure 15. It is evident from these relations that there are two separate gumbotils and that the gravel deposits are associated with the lower one.

The Nebraskan gravel deposits in Benton county are about 50 feet below the Kansan till surface but no exposures of Nebraskan gumbotil were observed with which to correlate them.

The Nebraskan gravel deposits of Fayette county are below the upland in a region of about 120 feet of relief, the upper one-third a result of irregular distribution of the Iowan till and loess. The Kansan gumbotil is at an elevation of 1110 feet above sea level in comparison with that of the Nebraskan gumbotil at 1040 feet above sea level, and that of the Nebraskan gravel at 1050 feet above sea level. These three exposures are within a radius of half a mile, as shown in figure 16.

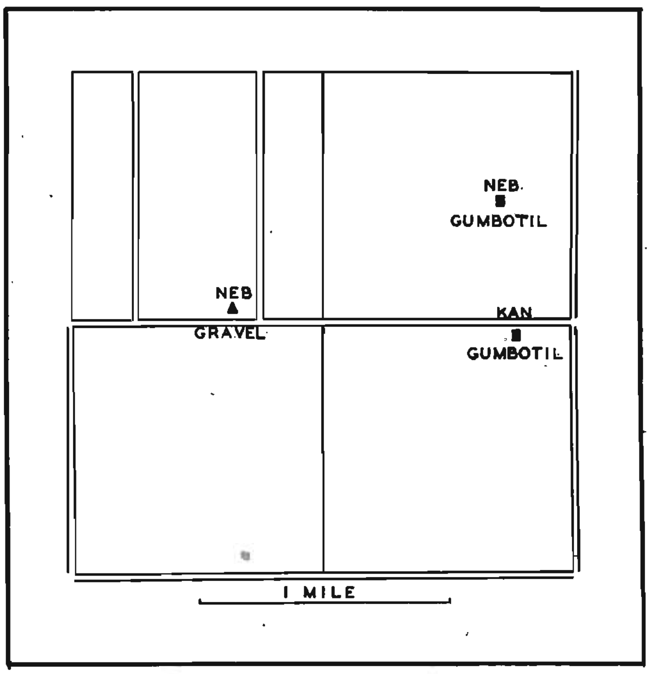


FIG. 16. — Sketch map showing locations of Nebraskan and Kansan exposures.

If the gumbotils were essentially horizontal or sloping slightly, the differences in elevation of the two gumbotil exposures would allow a thickness of about 70 feet for the Kansan drift. Since the gravel occurs at the same elevation as the Nebraskan gumbotil it may be assumed that the two are parts of the same plain. But correlating this gravel mass with the Kansan till would necessitate postulating either a minimum slope on the Kansan gumbotil surface of about 75 feet per mile or, if the surface was a plain as under normal conditions, leaching of the carbonates from 75 feet of overlying material and the 10 feet of gravel. The characteristics of the gravel show that it was deposited at the surface of the till, which would be in harmony with the correlation with the Nebraskan gumbotil plain.

The relations of the Nebraskan gravel of Chickasaw county are similar to those of the preceding exposures. It occurs in the valley, 55 feet lower than the level of the Kansan gumbotil plain which is on the divides. The physical characteristics of the gravel indicate that it was deposited at the surface of a till sheet which would logically be the Nebraskan.

The relations of gravel to associated deposits in western Iowa have been included in the general discussion of these deposits on pages 49 to 58. However, the interpretation of the age of these deposits is based entirely on their relation to the Nebraskan gumbotil plain.

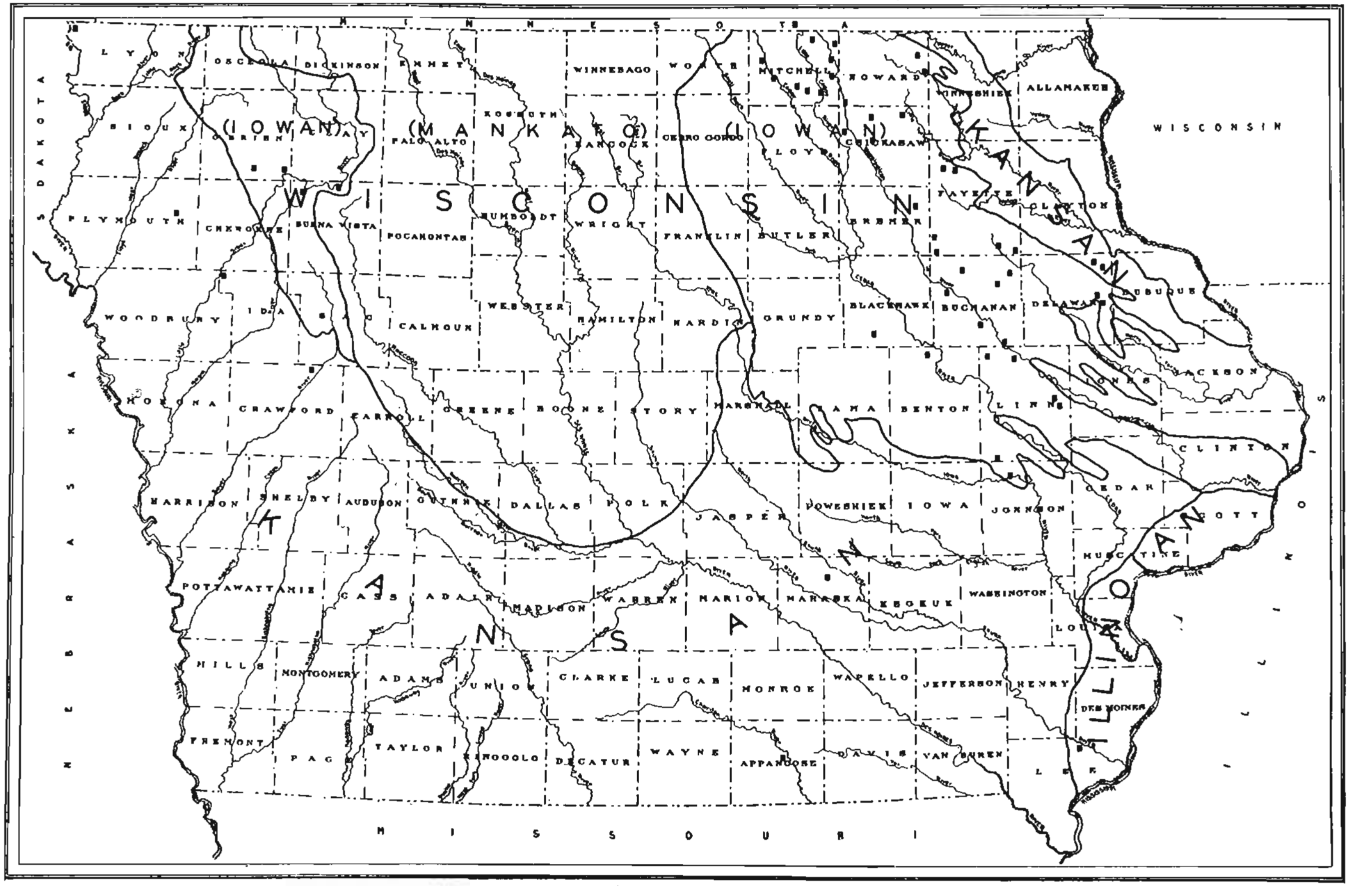
The Gravels of the Ottumwan Series — The Kansan and Yarmouth Stages

The gravels of the Ottumwan series include those deposited during the Kansan glacial age and the Yarmouth interglacial age. In almost all previous discussions these gravels have been referred to as Buchanan gravels.

Calvin,[80] who was the first to use the name Buchanan, made the following statements regarding the term:

"The use of the term Buchanan as a name for an interglacial stage is open to criticism. It came into use tentatively before the recognition of the Illinoian drift as a stage distinct from either Kansan or Iowan had been published, and when the whole period of time between the retreat of the Kansan and the invasion of the Iowan ice was supposed to be a single, uninterrupted, interglacial interval. It was first used in the precise sense

80 Calvin, S., The Interglacial Deposits of Northeastern Iowa: Iowa Acad. Sci., Vol. V, pp. 64-70, 1898, and American Geologist, Vol. XXI, pp. 251-254, 1898.



MAP OF IOWA

FIG. 17. — The squares show the locations of Nebraskan and Kansan exposures.

in which the term Aftonian was originally used, and as a substitute for that term when it was shown that the Aftonian soils and gravels preceded the Kansan stage. Since the recognition of the Illinoian glacial stage the term has been used for the interval following the Kansan in publications by Chamberlin, Calvin and Scott. No great objection to its continued use can be urged; in fact, it is much to be desired that names once introduced should remain undisturbed, but it may after all be a decided gain to Pleistocene geology to select a name for the interval between the Kansan and Illinoian from some locality where true interglacial deposits are clearly intercalated between the Kansan and Illinoian sheets of drift."

It is evident from the preceding reference that as early as 1897 Calvin realized that the old term should be replaced by new terms. In present usage, Buchanan represents that time interval between the retreat of the Kansan glacier and the advance of the Iowan.

The term was originally applied to gravels deposited during the retreat of the Kansan glacier. It did not include those gravels deposited during the Yarmouth interglacial age or the Buchanan interval. Furthermore, more recent investigations reveal that many of the gravel deposits called Buchanan in some of the early reports belong in reality to other ages of deposition. In this paper the "Buchanan gravels" will be described under their time of deposition.

The Distribution of the Gravels of the Kansan Stage

The Kansan gravels in Iowa are distributed throughout the area of Kansan glaciation. Most of the exposures are in gravel pits, but a few are in road cuts or in natural exposures along streams. As shown in figure 17, most of the exposures are in northeastern Iowa. Their absence in certain parts of the state is not always indicative of the absence of the gravel, but may be due either to the overlying material, which is too thick to permit the gravel to be profitably removed, or to the diminutive size of the gravel masses which renders them too small to be of commercial value. However, these small deposits are sometimes exposed in fresh road cuts or along streams. In northwestern Iowa many deposits near the surface of the drift must have been removed by erosion during the Loveland interval.

The Characteristics of the Gravels of the Kansan Stage

General Characteristics:

The Kansan gravels were deposited either as pockets within the till or as outwash at the surface of the till. Most of the exposures studied were deposited either at the surface or as pockets only a few feet below the surface, in either case having the same topographic position as the Kansan gumbotil. However, a few exposures are masses of gravel which were deposited lower down within the drift sheet.

Following the retreat of the Kansan glacier the Yarmouth interglacial age began, during which time the newly exposed drift surface was subjected to the modifying agencies of weathering. The atmosphere and ground water began altering the drift by oxidation and leaching, the oxidation taking place more rapidly and extending deeper than the leaching. In areas which were so situated topographically that there was little if any erosion, the zones shown in figure 8 were developed — namely, gumbotil, oxidized and leached till, oxidized and unleached till, and unoxidized and unleached till. The Kansan till was altered to gumbotil to an average depth of 11 feet. Leaching removed the carbonates from the till to an average depth of about 5 1/2 feet below the gumbotil, and the iron compounds were oxidized to still greater depths. While the till was being altered as described above, the sands and gravels within this zone of weathering were subjected to the same processess and underwent comparable alterations. The coarse texture of the gravel and sand in comparison with the till allowed oxidation to continue more rapidly and to greater depths, and the action of ground water in leaching was not disturbed by the formation of an impervious layer of gumbotil at the surface. The present altered condition of the gravel depends upon its relation to the original till surface.

Most of the exposures occur at and near the Kansan gumbotil plain, and show extreme alteration by both oxidation of the iron compounds and leaching of the carbonates; but the few exposures which occur as masses buried deeply within the till are unleached and may or may not be colored by the extreme oxidation of the iron compounds. The general characteristics will be given separately for each of the above types of gravel.

In the Kansan gravels which are at and near the Kansan gumbotil surface, the iron oxide forms a hard, harsh coating on the grains, colors the gravel to a dark reddish-brown (15'i, Ochraceous-Tawny to 15"i Sayal Brown), and cements it into a compact mass which will stand in a vertical section. After exposure to the air the iron oxide in the outer few inches hardens, making that part of the deposit more coherent. Extreme oxidation of the iron compounds within separate layers cements them more firmly into a weakly coherent conglomerate which can be broken into blocks. Leaching processes have removed the carbonates from all exposures of Kansan gravel of this type. Only those exposures buried deep within the till are unleached. The greatest depth to which the leaching within the Kansan gravel has been observed is about 55 feet. In addition to the complete removal of the more soluble rocks such as limestone and dolomite, many of the granites, greenstones, and other igneous rocks are disintegrated or weathered beyond identification.

The beds of gravel are well stratified in a general horizontal position but include irregularities in the form of lenses, pockets, cross-bedding, clay-balls, and masses of till. Although most of the exposures are well stratified, the poor sorting, the leaching, and the high degree of oxidation give some of them a massive, poorly stratified appearance. The deposits show a wide clastic textural range both within the separate exposures and in the group as a whole. Most of the gravel is smaller than 1.5 centimeters in diameter, although there is also a high percentage between 1.5 and 5 centimeters in diameter. Still larger than the pebbles are cobbles and boulders distributed through the finer material and seldom bearing any relationship to the stratification. Boulders having a diameter between 45 and 60 centimeters are not uncommon, and some have been observed with diameters as great as one meter. The percentage of the different size grades as determined by mechanical analyses is shown graphically in figure 18, each sample used represents an average of the exposure from which it was taken. The exposures represented in figure 18 are the type exposures described later in this report and other exposures included merely for comparison. The shape analyses of the different size grades of the first eight samples given in figure 18 are shown in figure 19. The rock content, determined from pebble counts made from the same exposures as represented in figure 18, is given in figure 20.

The type area in which to study the Kansan gravel is in Mitchell county, Iowa. In no other part of the state are their relations to the Kansan and Iowan tills so well shown. Kansan gravel underlying Illinoian till is best represented in Lee county, and the masses of Kansan gravel which were deposited deep within the Kansan till are exposed in the loess-mantled Kansan area in northwestern Iowa.

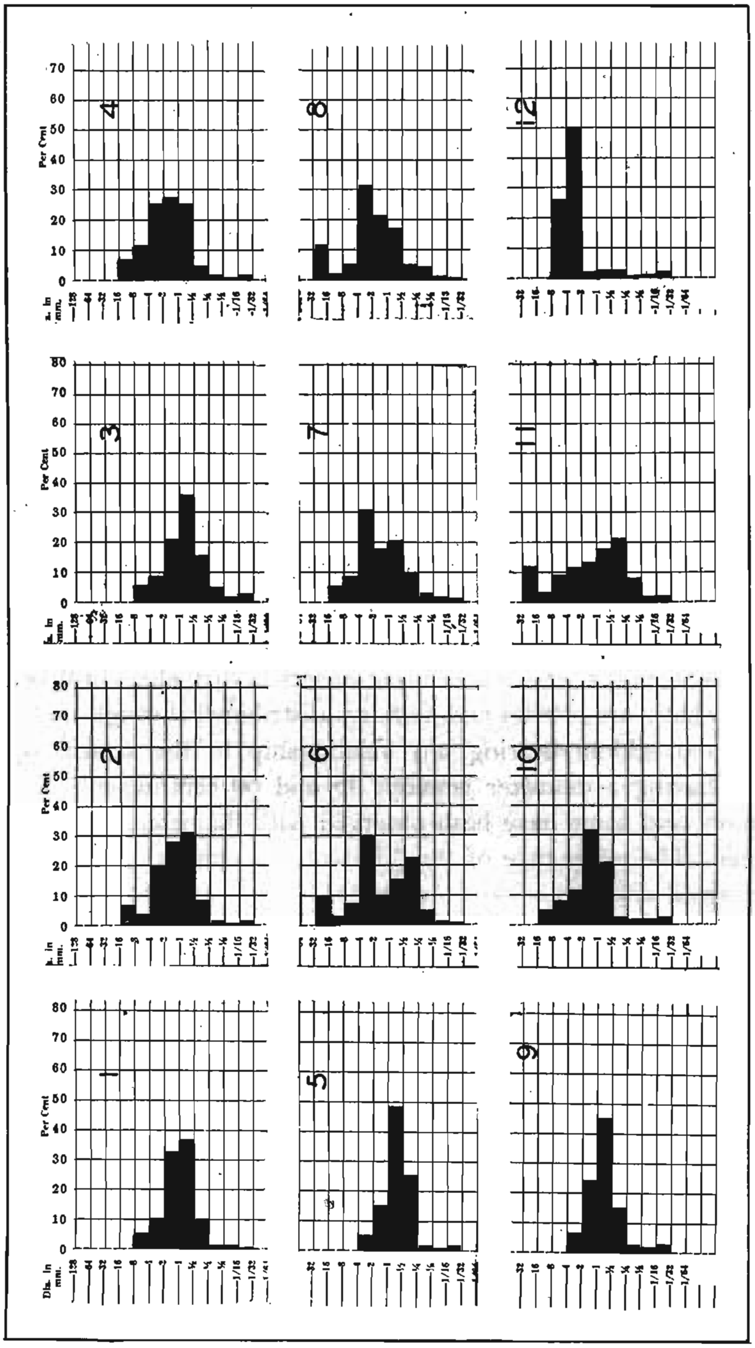


FIG. 18. — Graphs showing mechanical analyses of Kansan gravels. The numbers of this figure correspond with those of figures 19 and 20

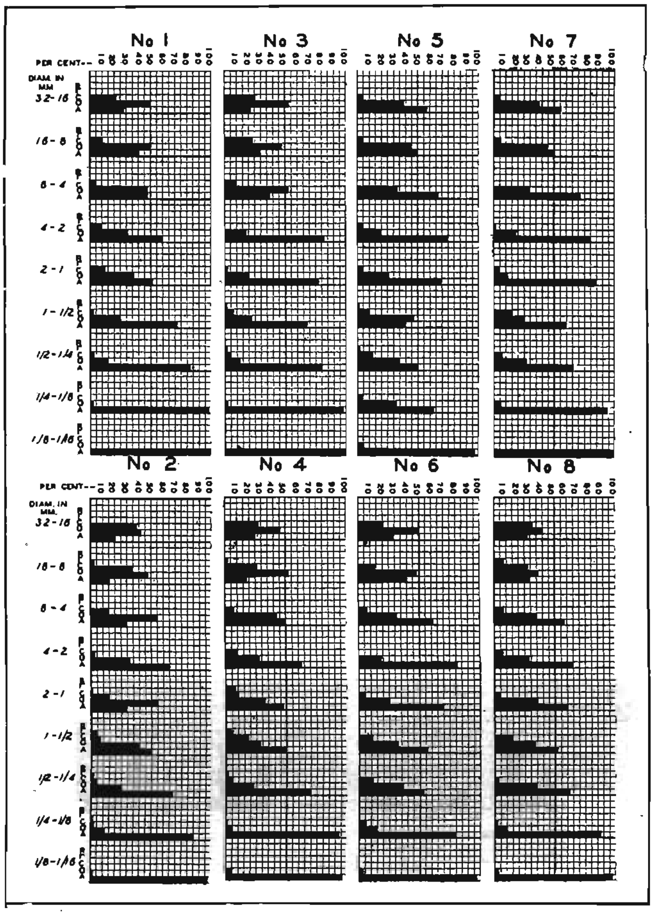


FIG. 19. — Graphs showing shape analyses of each size grade between 1/16 and 32 millimeters in diameter of Kansan gravels. The numbers of these analyses correspond with the numbers of the analyses of figures 18 and 20. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

Characteristics of Kansas Gravels in Northeastern Iowa:

The largest pit exposing Kansan gravel is in the southeast quarter of section 21, Burr Oak township (T. 98 N., R. 16 W.), Mitchell county, about 3 miles east of Osage. Here at the top of a low gently sloping rise, at an elevation of 1170 feet above sea level, in a region of gently rolling Iowan drift topography, is the large pit shown in figure 21, which is more than 35 feet deep. The total thickness of the gravel here is 55 feet, as was determined by boring to its base from the deepest part of the pit.

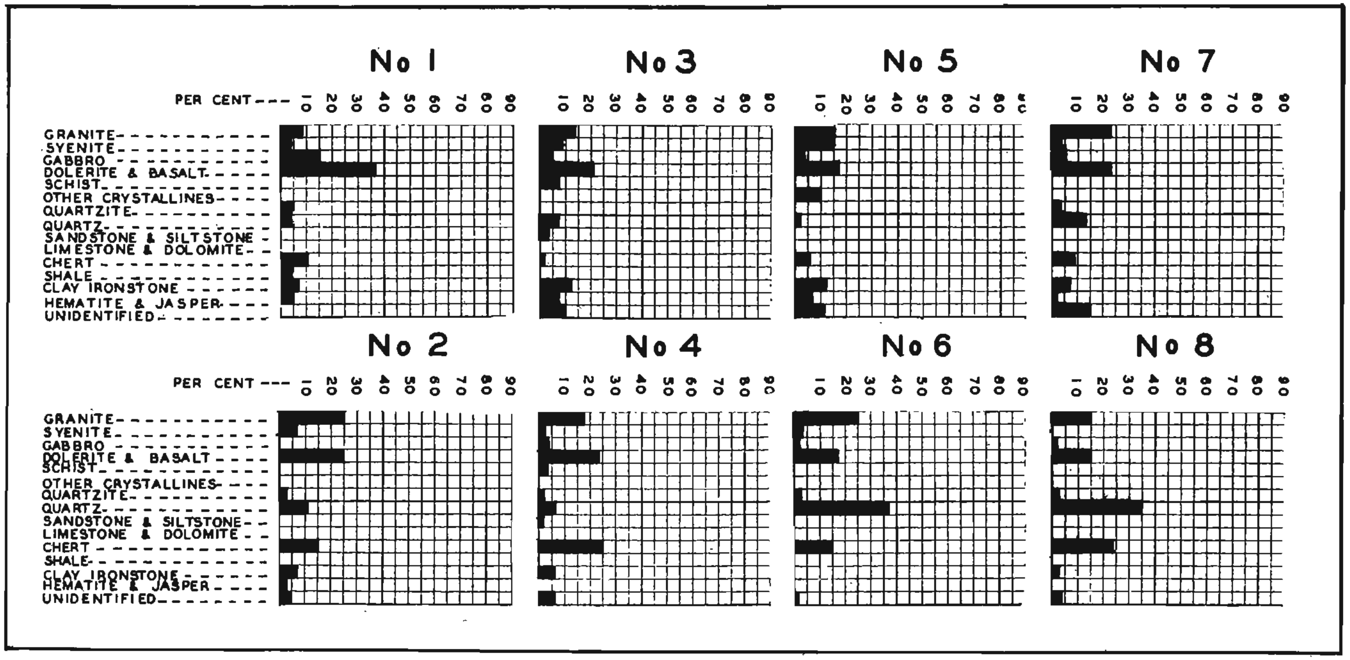


FIG. 20. — Graphs showing lithology of pebbles of Kansan gravel between 16 and 32 millimeters in diameter. The numbers of these analyses correspond with those of figures 18 and 19.

FIG. 21. — Kansan gravel pit about 3 miles east of Osage, Mitchell county.

The gravel is colored by iron oxide to a uniform medium brown (15'i, Ochraceous-Tawny to 15"i, Sayal-Brown) throughout the pit, except in one bed 8 inches thick near the base, which is more highly oxidized to a reddish-brown (12'm, Chestnut) and cemented into a firm mass which can be broken into fragments. Leaching has removed the calcium carbonate from the entire 55 feet of gravel in the section. Many of the igneous rocks are disintegrated and there are some secondary iron concretions. Almost all of the gravel is smaller than one centimeter in diameter. There are several boulders in the bottom of the pit which were uncovered while removing the gravel, most of them smaller than 30 centimeters in diameter. This pit will not average one stone larger than 13 centimeters in diameter to each 2000 yards of gravel. The percentage of each size grade, determined by a mechanical analysis is shown in No. 1 of figure 18. The percentage of rounding of each size grade between 1/16 and 32 millimeters in diameter is shown in No. 1 of figure 19. The lithology of pebbles between 16 and 32 millimeters in diameter is given in No. 1 of figure 20. The gravel shows good stratification in beds which are almost horizontal. Within these beds there is cross-bedding which dips at an angle of about 15 degrees in almost any direction, with the predominating direction southeast. The extreme weathering of the deposit renders the structure indistinct, making it appear almost massive in some parts. The gravel is overlain by a 4-foot layer of weathered Iowan till, leached and colored by iron oxide to a light buff-brown (19"i, Isabella Color) at the base and by the addition of humus to a chocolate-brown (17" ', Wood-Brown) at the surface.

Another deposit of Kansan gravel is in the southeast quarter of the northwest quarter of the same section as the exposure just described. It is at the same elevation (1170 feet above sea level) and there is only a slight sag between them. Here the gravel has been removed to a depth of about 12 feet. The exposed gravel differs from that of the deep pit, which is about one-half mile to the southwest, in that it contains many cobbles and boulders. The stratification is horizontal as in the preceding pit and the greater percentage of the cross-bedding dips toward the southeast.

Another exposure of Kansan gravel in Mitchell county is in the southwest quarter of section 10, Newberg township (T.99 N., R. 18 W.), about 2 miles northwest of St. Ansgar. Here in a gravel pit, near the top of the hill in a region of gently rolling Iowan drift topography, the Kansan gravel is exposed at an elevation of 1178 feet above sea level.

The 20 feet of gravel exposed is leached of its carbonates, colored by oxidation to a medium-brown (15'i, Ochraceous-Tawny to 15"i, Sayal Brown), and cemented into a firm mass. Within the major strata of the gravel there are some thin beds colored black by grain coatings of manganese dioxide, and other much thicker beds, colored a much deeper reddish-brown than the rest of the gravel mass. These beds are cemented into a firm conglomerate. The pebbles show the usual amount of disintegration by weathering and some may be broken easily by slight pressure. Most of the material is sand and fine gravel. The percentage of each size grade is shown in No. 2 of figure 18. The percentage of rounding is shown in No. 2 of figure 19. The lithology is given in No. 2 of figure 20. The gravel is well stratified in almost horizontal beds, and cross-bedding within the major beds dips toward the west. The base of the gravel is exposed in two places. In the north side of the pit the gravel overlies dark-gray till, leached of its carbonates only in the upper 6 inches. In the south side of the pit the gravel overlies limestone bedrock. The over burden is leached Iowan till, 2 feet thick and colored to the usual chocolate-brown by oxidation and humus.

In Mitchell county, about 3/4 mile east of McIntire, in the northeast quarter of section 35, Wayne township (T. 100 N., R. 15 W.), Kansan gravel is exposed along the hillside about 25 feet below the upland, at an elevation of 1300 feet above sea level, in a region of gently rolling Iowan drift topography. The 12 feet of gravel exposed is leached of its carbonates, and exhibits the usual oxidation and weathering. The màterial consists almost entirely of sand and fine gravel which is well stratified, generally in horizontal beds with some cross-bedding within the thicker beds. The percentage of the different size grades of a representative sample is shown in No. 3 of figure 18. The percentage of rounding is shown in No. 3 of figure 20. There is no visible contact at the base of the gravel with the underlying material, but the top of the gravel is overlain by both Loveland silt and Iowan gravel. The 6-inch bed of Loveland silt lies between the Kansan and Iowan gravels in the south half of the exposure, while along the northern border the silt has been plowed up and incorporated in the base of the overlying Iowan gravel. In the north part of the exposure the Kansan gravel is directly overlain by the Iowan gravel, each having distinctly different characteristics. The Iowan gravel and overlying Iowan till have a combined thickness of about 7 feet and only the upper 5 feet have been leached of their carbonates. The coloring and cementation by oxidation, and the amount of weathering. is much less in the Iowan than in the underlying Kansan gravel. Likewise, the Iowan gravel appears to be poorly stratified, because of the poor sorting of the material, which has an average diameter more than twice that of the Kansan gravel.

About 2 miles north of Osage, in the southwest quarter of section 12, Mitchell township (T. 98 N., R. 17 W.), Mitchell county, Kansan gravel is exposed in a gravel pit at an elevation of 1152 feet above sea level, on a wide flat divide covered with Iowan drift.

The gravel of this pit shows the same general characteristics as the gravel of the pits previously described. They are colored to a medium-brown (15'i, Ochraceous-Tawny to 15"i, Sayal-Brown), and leached to the base of the 20-foot exposure. The material is mostly sand and fine gravel smaller than 2 centimeters in diameter, although there are a few boulders, the largest 60 centimeters in diameter. Size, shape, and rock analyses are given in No. 4 of figures 18, 19 and 20. Along the north side of the pit, below a 2-foot layer of weathered Iowan till, is an exposure of Kansan gumbotil. It is not an inclusion of till but represents the lateral contact of the gravel with the Kansan till which has been altered to gumbotil. This relationship shows that the gravel was deposited as an irregular mass within the till at the surface of the Kansan drift plain.

Another interesting pit in Mitchell county in which Kansan gravel is exposed is along the county road about 3 miles north of Stacyville. in the northeast quarter of section 18, Stacyville township (T. 100 N., R. 16 W.). Here the gravel is exposed along the hillside only a few feet below the upland, in a region of gently rolling Iowan drift topography, 1230 feet above sea level.

The oxidation has colored the gravel to various shades of brown and buff, the color varying with the kinds of material. The carbonates have been leached from the entire 15 feet of gravel, and the usual weathering of the igneous rocks can be observed. The deposit may be roughly divided into two members. The upper 8-foot member consists chiefly of irregularly bedded sand and fine gravel with less oxidation than the average Kansan gravel deposits. It contains three large masses of gumbotil, the largest 15 feet across at the base and 8 feet high as shown in figure 22. The lower bed of gravel is of the usual type in oxidation, leaching, and uniform stratification. Size, shape, and lithologic analyses of average material from the lower 7 feet are given in No. 5 of figures 18, 19 and 20. The gravel

FIG. 22. — Large mass of gumbotil inclosed within the Kansan gravel.

is overlain by a bed of gravelly Iowan till 2 feet thick which is leached and colored to the usual chocolate-brown (17'' ', Wood-Brown) by oxidation and humus. Kansan gumbotil overlain by Iowan till is exposed in the road cut about 100 feet west of the gravel pit and in another road cut three-fourths of a mile south of the gravel pit, both at the same elevation as the gravel. This relationship of the gravel to the gumbotil plain shows that the gravel was deposited as a pocket at the surface of the Kansan till.

In Minnesota, a short distance north of the Iowa boundary, is a large pit in Kansan gravel. It is in the northwest quarter of section 23, Mower township (T. 10 N., R. 17 W.), Adams county 6 1/2 miles northwest of Stacyville. The gravel is exposed at an elevation of 1260 feet above sea level, a few feet below the upland of gently rolling Iowan drift topography.

The coloring by oxidation varies throughout the exposure; in some parts where the material is almost entirely quartz sand, coloring is seldom darker than light-buff, but in other parts of the exposure where other kinds of rock are present the gravel is colored to various shades of brown. The material consists chiefly of sand and fine gravel, well stratified and with considerable cross-bedding. Nothing observed in the pit was coarser than 12 centimeters in diameter. Size, shape, and lithologic analyses are shown in No. 6 of figures 18, 19, and 20. In the south side of the pit the beds of Kansan gravel have been folded and crumpled by the overriding Iowan glacier. Sand and till were deposited in the troughs and some of it is still unleached. Near the southeast corner of this pit there was in 1927 about 6 feet of calcareous sand, gravel, and till interlayered with leached materials of like kind, which represents the Iowan drift deposited in this area. There were 22 feet of leached sand and gravel exposed below the Iowan calcareous material.

In addition to the pits already described five other Kansan gravel pits having similar characteristics were studied in Mitchell county. In these, no contacts with associated materials were observed other than the thin layers of oxidized and leached Iowan till which usually overlie the gravel within the Iowan area. The most significant feature of these exposures is their comparable elevation, topographic position, and physical characteristics, which enable them to be correlated with the Kansan exposures previously described.

As will be shown in the following descriptions, the characteristics of the Kansan gravels in other parts of northeastern Iowa are similar to those of Mitchell county.

One of the exposures of Kansan gravel in Howard county is in the southwest quarter of section 26, Vernon Springs township (T. 99 N., R. 11 W.), in the south side of Cresco. Here the Kansan gravel is exposed in a gravel pit on the upland at an elevation of 1280 feet above sea level, 25 feet lower than the Kansan gumbotil exposed 2 miles to the northwest.

The 20 feet of gravel exposed in this pit is uniformly colored to a medium-brown (15'i, Ochraceous-Tawny to 15"i, Sayal-Brown) by the iron oxide which cements the gravel into a compact mass that stands as a vertical wall. Leaching has removed all of the carbonates, and weathering has disintegrated many of the granites, greenstones, and other igneous rocks. The deposit is chiefly sand and gravel smaller than 3 centimeters in diameter, deposited in horizontal beds which contain some cross-bedding. Several boulders, the largest having an average diameter of 75 centimeters, are scattered through the gravel mass. A mechanical analysis of the material is shown in No. 7 of figure 18, and the percentage of rounding is shown in No. 7 of figure 19. A rock analysis, is given in No. 7 of figure 20. The gravel lies between limestone bedrock, which is exposed in the base of the pit, and oxidized and leached Iowan till which has a maximum thickness of about 5 feet.

About 1/2 mile north of Fairbanks, in the northwest quarter of section 33, Oran township (T. 91 N., R. 10 W.), Fayette county, Kansan gravel is exposed in a pit located near the upland at an elevation of 1020 feet above sea level, in a region of gently rolling Iowan drift topography.

The gravel of this 15-foot exposure is similar to that of exposures previously described, except that it contains numerous ironstone concretions and several irregular masses of till that have been altered to gumbotil. The size, shape, and lithologic analyses are given in No. 8 of figures 18 to 20. In the underlying material, in a tile ditch at the base of the north side of the pit, the upper 3 inches is leached of its carbonates and resembles gumbotil, but below this the till is dark-gray (15"", Mouse-Gray) and neither leached nor oxidized. The overburden is weathered Iowan till only 2 feet thick.

Characteristics of Kansan Gravels in Southeastern Iowa:

In part of southeastern Iowa the Kansan deposits are overlain by the thick layer of Illinoian drift and the still younger Peorian loess. Here in a small valley in section 20, Denmark township (T. 69 N., R. 4 W.), Lee county, is a pocket of Kansan gravel with its relations to the surrounding Kansan drift and younger overlying Illinoian drift clearly exposed.

This Kansan sand and gravel deposit is 30 feet thick and shows a distinct difference between the material of the lower 8 feet and that of the upper 22 feet.

The lower 8 feet of the exposure has a distinct blue-black color when moist, with only slight variations throughout its thickness. The material is fine sand except for one 6-inch bed which contains coarser sand but no gravel. The sand is well stratified in very thin beds in which small folds have been developed in many places. In the structure, also, there are minor irregularities such as lenses and cross-bedding. The only coloration by iron oxide is faint concentric bands that have no correlation to the general structure.

The upper 22 feet of the exposure is coarse sand and fine gravel including only a small percentage of pebbles. Nothing larger than 5 centimeters in diameter was observed and pebbles larger than 2 centimeters in diameter are not common. The stratification is good but lens structure and cross-bedding are common within the major beds. In the upper 3 feet an increase in the percentage of clay and of pebbles scattered through the gravel gives it a more massive structure. Oxidation of the iron compounds colors the gravel reddish-brown (15"m, Bister), and cements it into a compact mass in the lower 19 feet, while in the upper 3 feet the oxidation is greater and cements the gravel into a firm, friable conglomerate. The greater oxidation of the upper 3 feet of gravel appears to be the result of its having a higher percentage of clay than the lower 19 feet has, the clay being more readily oxidized, and the clay and iron oxide filling the interstitial space.

Leaching during the Yarmouth interglacial age, before the deposition of the Illinoian drift, has removed the carbonates from the entire 30 feet of gravel. However, the underlying Kansan till is blue-black when moist, and unleached. No distinct line separates this till from the overlying sand, but between them is a sandy till gradation, about 6 inches thick, which is not entirely leached. Descending ground water has carried calcium carbonate from the unleached Illinoian drift above and deposited it as secondary lime concretions in the upper few feet of both the leached Kansan gravel and the till. Marginally, where observed, the gravel grades into the Kansan till, which contains a carbonaceous layer about one foot thick at its surface. This carbonaceous zone represents what was an old soil surface during Yarmouth interglacial time and it likewise shows that the Kansan gravel was at or near the surface of the Kansan till during this interval and thus subjected to the same weathering processes as the till.

Characteristics of Kansan Gravels in Northwestern Iowa:

In northwestern Iowa, the erosion during the interval following the development of the Kansan gumbotil and before the coming of the Iowan glacier removed the gumbotil and leached Kansan drift, leaving at the surface oxidized and unleached drift upon which the Iowan drift and loess deposits were laid down. This erosion removed any gravel deposits which like those described in eastern Iowa were deposited at or near the surface of the Kansan drift. Thus the unleached Kansan drift left at the surface upon which the younger deposits, also unleached, were deposited makes it difficult to differentiate between the Kansan and younger Iowan drifts. Throughout most of the Kansan drift area the overlying deposits of Iowan drift or loess, or both of them, bury the Kansan to such a depth that there are few Kansan exposures either artificial or natural. This likewise limits the number of Kansan gravel exposures, which in their unleached condition as pockets in the Kansan till are difficult to differentiate from the Iowan gravel. This difficulty is overcome in the loess-Kansan area beyond the Iowan drift region.

During the field seasons of 1909 and 1910, and parts of the field seasons of 1911, 1913, 1916, and 1927, Carman [31] made an intensive study of the Pleistocene deposits in northwestern Iowa. In his report on this area he describes several exposures of Kansan gravel, most of which are completely obscured by slump and growth of vegetation at the present time, but even in those studied it seems unnecessary to attempt to improve upon his descriptions. He describes them as follows:

[31] Carman, J. E., Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 111-114, 1931.

"There is in the till of northwestern Iowa a large quantity of gravel and sand in the form of inclosed masses (gravel bowlders). These are known in both the Kansan and Iowan drift regions and are apparently inclosed in both the Kansan and Iowan tills, although it is not possible in most cases to distinguish these tills. These gravel masses were observed in cuts and in the fresher and steeper valley-side exposures. When they are penetrated by bored or drilled wells they are usually reported as gravel layers, but in dug wells their true nature is revealed in most cases. Most wells which stop in gravel masses fail to furnish an adequate supply of water.

"The gravel masses range in size from small pockets a few inches across to huge masses 10 to 20 feet or more in diameter. Common dimensions are three to six feet. A mass exposed in a railway cut in section 6 of Douglas township, Ida county, about 1 1/2 miles south of Washta, is about 35 feet by 20 feet on the face of the cut and another in a Chicago and Northwestern railway cut just east of Sioux Rapids is 20 to 25 feet across.

"Most of the sand and gravel masses are roughly equidimensional or compressed in a vertical direction, but some are irregular in shape. Most of them have a rounded form, but several were seen with corners projecting into the till in such ways as could have been assumed only when the gravel masses were frozen.

"The sand and gravel of the bowlders are, as a rule, stratified. The beds range in position from approximately horizontal to vertical, and locally the layers are contorted. The bedding of a particular bowlder is usually a unit, but a few cases were observed which show faulting and some crushing, and in many cases the bedding is obliterated at the margins of the mass.

"The material of these bowlders is sand, fine gravel, and some silts. Most of it is slightly ferruginous so that an iron-stained dust is released when the gravel is displaced. There are a few masses composed of strongly rusted gravel. In general, the coarse gravel is rusted and partly decomposed, while the finer material is fresh and unaltered. The coarse-grained igneous pebbles are more decomposed than the finer-grained ones and the darker colored varieties (containing mica and hornblende) more than the lighter colored. Most limestone pebbles are altered slightly at the surface and a few are altered to the center or decomposed to clay ironstones.

"Seventeen analyses of gravel associated with till were made, but there is some question concerning the correct interpretation of a number of these gravel bowlders. The analyses of the ten positive cases average 38 per cent igneous and 62 per cent sedimentary rocks, 50 per cent being limestone. The average of the seventeen analyses is 41 per cent igneous rocks and 59 per cent sedimentary. Small rounded balls of till (clay-balls) were seen in a few of the gravel bowlders.

"In most cases the till is fresh up to the edge of the gravel bowlders, but in a few cases a thin shell, concentric with the border, is stained, altered, and partly cemented with ferruginous material. Also in a few cases the gravel is cemented in a shell around the outside of the mass. This alteration and cementation is a contact phenomenon which has been produced since the inclusion of the gravel mass.

"Description of Some Typical Gravel Masses

"Little Sioux river valley across northern Buena Vista and southern Clay counties has been cut deeply into the till, and both natural and artificial exposures along the valley show many gravel bowlders. This is in the Iowan drift region, but an Iowan drift cannot commonly be differentiated from the Kansan, and the till of these bluffs is quite certainly Kansan. A large sand bowlder in a cut of the Chicago and Northwestern railway just east of Sioux Rapids has been noted above (page 105), and gravel masses are numerous in several cuts a little farther east. In the southeast quarter of section 3, Barnes township, Buena Vista county, just east of where the railway crosses the terrace area, is a cut which, although old and slumped, shows a great number of sand bowlders.

"Near the top of the bluff north of the schoolhouse at Peterson, there is a pit excavation 30 to 40 feet across and 15 to 20 feet deep. The material excavated was supplied by several large sand and gravel bowlders packed closely together. Some of the vertical contacts with the inclosing till were exposed. Some of the material is coarse gravel, some is fine sand, and some is silt. The material is stratified, and the beds now stand at various angles. Near the top of the slope leading to the upland southwest of Peterson the road cut exposed a lens of sand 50 feet long and 10 feet thick. The material is slightly iron-stained and around the edges of the mass is somewhat contorted.

"A large sand bowlder was exposed in a road cut on the slope toward the river in the north half of section 26, Waterman township, O'Brien county, and at about the center of section 14 of the same township the east bluff of Waterman creek showed several gravel bowlders, 4 to 10 feet across, inclosed in Kansan till.

"Just east of the center of section 22, Brooks township, Buena Vista county, the west bank of a ravine exposed an old looking ferruginous sand and gravel with some fine silty layers. The exposure had a length of about 50 feet and rose 40 feet above the ravine bed to the top of the slope. In either direction the ravine slope was grassed over and the basal part of the exposure was too badly slumped to show material in place, but Kansan till was exposed in the ravine bed just south of the exposure and rose to eight feet above the ravine bed just north of the exposure. There is little doubt that this is a great gravel mass included in the Kansan till. The bedding of the mass dips slightly to the south and apparently back into the bank to the west. Ferruginous concretionary cementation has affected part of the sand and has formed irregular shaped masses, some of which are more than a foot across. The material composing the mass is much more decomposed and altered than is common for the gravel masses.

"In the north bluff of Storm Lake, near the center of section 4, Hayes township, Buena Vista county, there are several irregular masses of loesslike silt and sand. At several places the layers making up the masses are contored and crumpled and even broken off, so that they abut against other parts of the mass in which the layers have a different angle.

"In the north part of Cherokee, in an alley just east of Second Street and south of Spruce Street, a bank showed a large mass of silt and sand partly inclosed in till. The material is somewhat contorted and the layers are in part steeply inclined. This exposure is probably Iowan drift. A series of road cuts in Kansan till in the northeast quarter of section 28, Cherokee township, showed in 1916 a large number of inclosed gravel masses. The face of one of these cuts near the north line of the section showed almost as much gravel as till.

"Other gravel masses were seen in the south bluffs of Mill Creek between the bridges in the northeast quarter of section 23, Cherokee township; in the bluffs of the creek valley of section 24, Cedar township; along the creek valley through sections 11 and 10, Pilot township, south of Cherokee; and at many other places throughout the area. In fact, most large exposures of till show some of these gravel masses. Most of the gravel masses so far described are in the Iowan drift region, but the Iowan drift is believed to be very thin and the gravel masses are apparently in the Kansan till.

"In the south bank of a ravine in the south part of section 10, Stockholm township, Crawford county, about a quarter of a mile west of the railway, there are several gravel bowlders four to ten feet in diameter and some smaller ones of sandy silt or silt. The material of these gravel bowlders is somewhat iron-stained and in one case the gravel around the border is partly cemented, while in another surrounding clay is iron-stained for two to three inches, concentric with the border of the bowlder. An analysis of pebbles from one of these bowlders gave 30 per cent igneous rocks and 70 per cent sedimentary rocks, 7 per cent of which were clay-balls. The layers of the gravel composing the bowlders are inclined.

"In the south bank of the road cut just east of the railway crossing in the east part of section 15, east of Sioux Falls, South Dakota, there is a mass of gravel completely inclosed in the Kansan till. The gravel is rather fresh and contains shale pebbles and drift pebbles. The analyses showed 49 per cent igneous rocks and 51 per cent sedimentary. The bedding of the mass is inclined."

Another exposure of gravel is in a gravel pit along the hillside in the northwest quarter of section 9, Remsen township, Plymouth county. This exposure is within the Kansan till, near the top of the hill, and is overlain by Peorian loess. Since it is outside the Iowan drift area, the possibility of Iowan age is eliminated.

The pit has not been worked for many years and the slump and vegetation have concealed most of the exposure. The gravel is well stratified in beds which dip primarily toward the southwest. Within the beds of sand and gravel, which are almost all finer than 2 centimeters in diameter, several pebbles, and cobbles having a maximum diameter of about 10 centimeters, are scattered with no definite relation to the stratification. The iron oxide coating the grains colors the mass to a medium-brown (17" ', Wood-Brown), which is not as dark as those gravels described in eastern Iowa. Cementation by iron oxide is not sufficient to cause the gravel to stand in a vertical section long after exposure; it slumps and soon conceals the structure. None of the gravel is leached, and limestone pebbles are distributed throughout the mass. This mass of gravel is quite large in comparison with the others of this type in this part of the state, and has supplied considerable road material. The dimensions are obscured by slumping, but its apparent diameter is more than 50 feet and its thickness more than 10 feet.

Relations of the Kansan Gravels:

It has been previously stated that the gravels deposited during the invasion of an ice sheet occupy positions at the base, within, and at the surface of the till. A very high percentage of the deposits are exposed at and near the gumbotil horizon.

Most of the Kansan gravels studied in northeastern and southeastern Iowa are near the surface of the Kansan gumbotil plain and have undergone changes comparable to those which altered the till to gumbotil. The gravels deposited deeper within the till sheet are exposed in northwestern Iowa. As a result of a long period of erosion which removed the gumbotil and the leached till, these deeply buried deposits have been brought nearer to the surface and now are exposed as unleached gravel masses.

Mitchell county, Iowa, represents the type area in which to study the relations of the Kansan gravels to the Kansan till and the over-

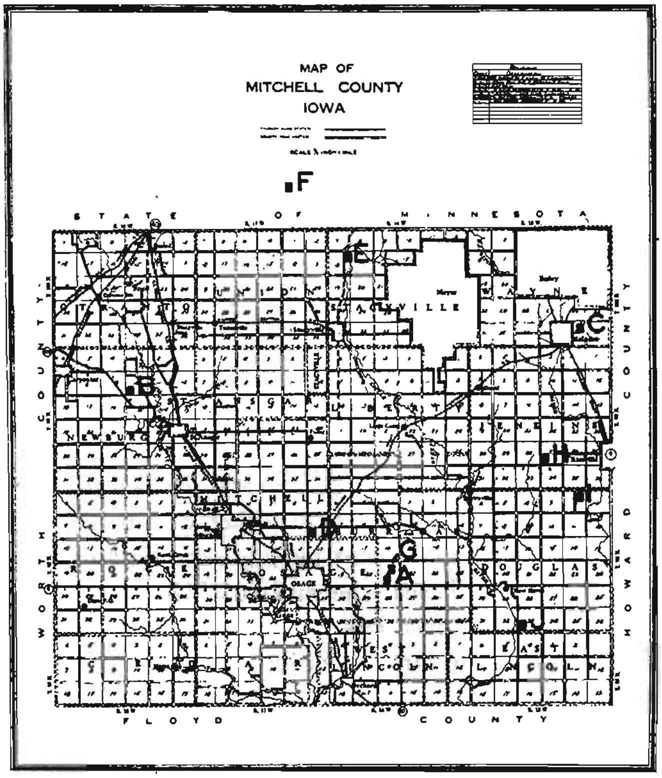


FIG. 23. — Map of Mitchell county, showing the distribution of Kansan gravel exposures studied.

lying Iowan till. Their areal distribution is shown in figure 23, and their elevations and relations to associated materials are given in the following table:

A. T. 98 N., R.16 W., sec. 21	1170	Iowan till Kansan gravel.
B. T. 99 N., R.18 W., sec. 10	1178	Iowan till Kansan gravel Fresh Kansan till and bedrock.
C. T. 100 N., R.15 W., sec. 35	1300	Iowan till Iowan gravel Loveland loess Kansan gravel.
D. T. 98 N., R.17 W., sec. 12	1152	Iowan till Kansan gumbotil Kansan gravel.

E. T. 100 N., R.16 W., sec. 18	1230	Iowan gravelly till Kansan gumbotil Kansan gravel.
F. T. 101 N., R.17 W., sec. 23	1260	Unleached Iowan till Kansan gravel.
G. T. 98 N., R.17 W., sec. 9	1175	Iowan till Kansan gravel.
H. T. 99 N., R.15 W., sec. 27	1240	Iowan till Kansan gravel.
I. T. 98 N., R.15 W., sec. 2	1190	Kansan gravel.
J. T. 97 N., R.15 W., sec. 33	1135	Iowan till Kansan gravel.
K. T. 98 N., R.16 W., sec. 21	1170	Iowan till Kansan gravel.

In two of the exposures (D and E) listed in the preceding table, gumbotil is exposed at the level of the top of the gravel deposit, proving that these deposits occupy a position at the level of the gumbotil plain and consequently have undergone alterations comparable to those of the till. In the north side of exposure D, the gravel is in contact with the gumbotil at the top and with oxidized and leached till lower down, showing that this deposit represents a pocket within the drift. At E, the gravel is exposed along the east hillside and contains some masses of till, altered to gumbotil, near the surface of the gravel (figure 22). In a road cut about 100 feet west of the gravel exposures, Kansan gumbotil is exposed at the same elevation as the top of the gravel and is overlain by a few feet of gravelly Iowan till. There is another exposure of Kansan gumbotil at the same elevation as the Kansan gravel in a road cut ¾ mile southwest. The topographic and geographic relations of the gravel exposures D and E to the Kansan gumbotil, and the characteristics of the gravel, afford conclusive evidence that they are directly related in age and origin to the Kansan drift deposition and were deposited at the surface of the drift.

The exposures A and K in the above table are about 4 miles from D and 18 feet higher, the difference in elevation suggesting that these also were deposited near the surface of the drift, as is further indicated by the leaching of the entire 55-foot section of gravel, which could not have been accomplished had the gravel been covered by a thick layer of Kansan till.

The characteristics and elevations of the other exposures of Kansan gravel listed in the preceding table are in harmony with this relationship to the Kansan drift.

In southeastern Iowa the exposure of Kansan gravel shows both a lateral and vertical gradation into the Kansan till and is related to the associated deposits in the section in the following manner:

2. Loess covering the slopes to an elevation of about 20 feet above the gumbotil on which it lies. The upper surface of the loess is at the upland.
1. Gumbotil, Illinoian, typical in all respects, 3 feet thick.

About 150 yards to the southwest is another exposure lower topographically, and showing the following:

2. Till, Illinoian, oxidized and unleached 7 feet
1. Till Kansan gumbotil-like more strongly oxidized than the till above. Much carbonaceous material in the upper 1 foot; leached, but having some secondary calcium carbonate along joints; grades laterally and vertically into the gravel and silts.

The position within the Kansan till, the gradation both vertically and horizontally into Kansan till, the comparable elevation of the upper gravel surface to that of the Kansan gumbotil and soil zone, and the amount of weathering within the gravel all lead to the same conclusion — namely, that the gravel is a pocket which was deposited at the Kansan drift surface.

The masses of Kansan gravel (gravel boulders) in northwestern Iowa are included within the Kansan till. These Kansan gravel deposits and Kansan till are unleached even to the base of the overlying Iowan till and loess, which indicates that the gumbotil and leached zone formed during the Yarmouth age had been eroded before the Iowan till and loess were deposited. If the weathering within the Kansan deposits in this part of the state before the erosion began was at all comparable to that in other parts of the state, the erosion must have removed almost as much from this surface as the amount of weathered material found in the Kansan drift underlying the next younger drift (the Illinoian) in southeastern Iowa — namely, 8 1/2 feet of gumbotil and 5 feet of leached till. If this assumption is true the gravel masses were deposited in the Kansan till at depths greater than 13 feet.

Age of the Kansan Gravels:

All of the gravel deposited in Iowa during the Ottumwan epoch is closely related to the Kansan till. There are some irregular masses removed from the overridden surface by the advancing Kansan glacier and deposited in the lower part of the till as the ice melted. Some of these masses picked up by the glacier were probably deposited originally by the waters from the advancing ice sheet, while others were deposited at an earlier time. Most of the Kansan gravel is in large irregular masses deposited directly within the Kansan till. Although some of these are buried deeply within the till, most of them are near the upper surface, the gumbotil horizon. All of the Kansan gravel deposits were left in their present position during the deposition of the till which was let down as the glacier melted.

The Gravels of the Centralian Series — The Illinoian and Sangamon Stages

The Centralian gravels were deposited during the Illinoian glacial and Sangamon interglacial ages, both types being directly related to the Illinoian glacier, and its deposition.

The Illinoian glacier crossed the Mississippi from the east and pushed westward a maximum distance of about 30 miles. Over a small area in southeastern Iowa (see figure 2) it deposited a layer of drift which has an average thickness of about 30 feet. The general character of the Illinoian drift is like that of the two older drifts, the Kansan and Nebraskan. The surface was a relatively flat plain upon which 4 to 6 feet of gumbotil was formed by weathering processes during the Sangamon interglacial age. Gravel deposits subjected to the same processes of weathering underwent changes comparable to those within the till.

In some places, erosion has dissected the gumbotil plain, and upon both the Illinoian gumbotil and the eroded surfaces two loesses have been deposited. The older loess is post-Illinoian gumbotil erosion pre-Iowan, and the younger is closely related in age to the retreat of the Iowan ice.

During the Centralian epoch two types of gravel were deposited in Iowa: (1) upland deposits associated with the Illinoian drift, and (2) lacustrine deposits beyond the drift margin. These lacustrine deposits were formed as a result of the glacier damming up several of the streams, making within their valleys a large lake which was not drained until shortly before the Iowan glacier advanced. This lake basin, Lake Calvin, has been described in great detail by Schoewe.[32]

Distribution of the Gravels:

The Illinoian upland gravels have been observed in only one exposure, which is near Muscatine, Iowa. Several small pockets of gravel

32 Schoewe, Walter H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 49-222, 1924.

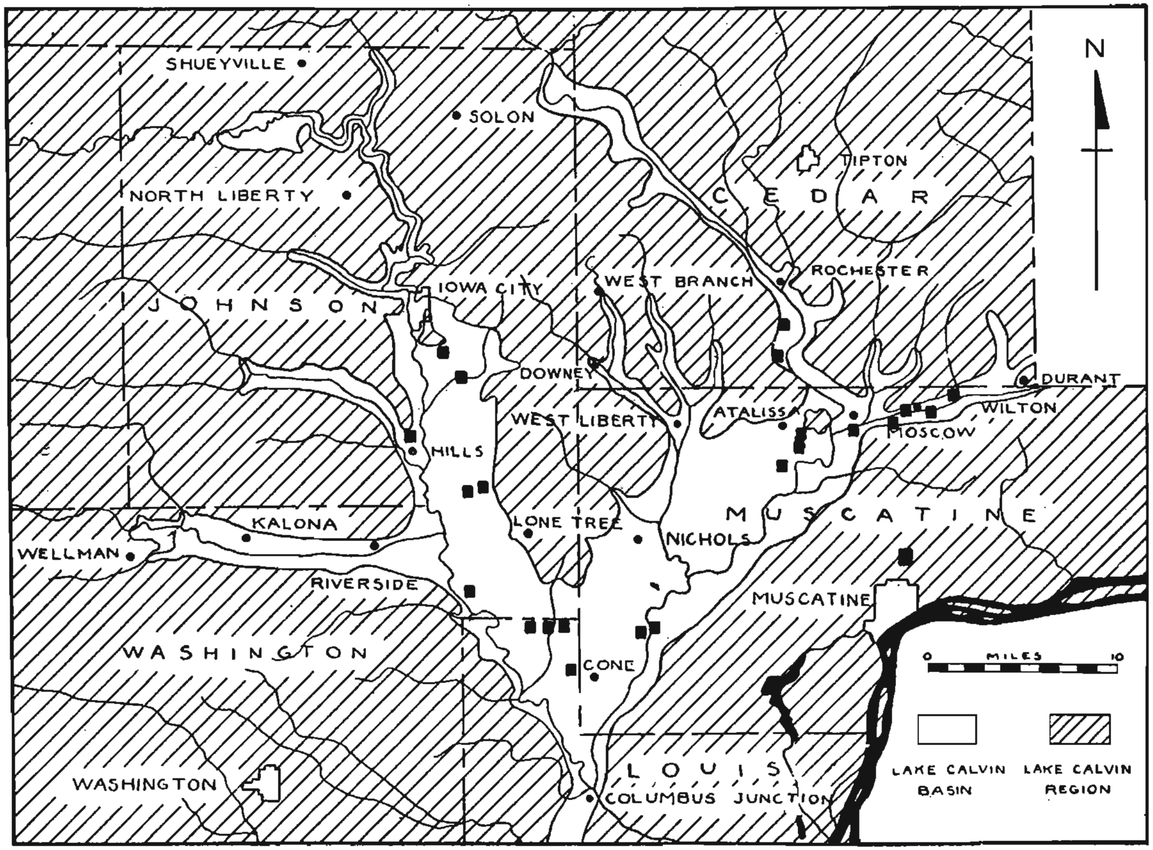


FIG. 24. — Sketch map of the Lake Calvin area showing the location and extent of the lake. The small squares show the locations of exposures described by Schoewe. (Map by Schoewe)

have been removed from the till at other locations, but at present these pits are slumped in and grassed over. Other masses of Illinoian gravel probably occur within the till but are deeply buried below the overlying loesses and possibly some Illinoian till.

The lacustrine silt, sand, and gravel were deposited in extinct Lake Calvin, which had the areal distribution shown in figure 24. In the discussion of the origin and history of this lake, Schoewe described the silt, sand, and gravel exposed at the locations shown in figure 24. A further discussion of the distribution of these deposits will be included with the generalized description of the lake basin.

Characteristics of the Illinoian Upland Gravel:

The only exposure in which the Illinoian upland gravel was studied is in the east half of section 23, Bloomington township (T. 77 N., R. 2 W.), Muscatine county. It is near the upland along the west side of Mad Creek valley.

Within the exposure, which covers more than an acre, the gravel shows a wide range in texture, structure, and degree of alteration. The greatest coloration by iron oxide is in the upper part. In the north end of the exposure the upper 4 feet are colored maroon (11'm, Chestnut-Brown), and cemented into a weakly coherent mass. In another part of the exposure a thin bed is colored maroon and cemented into a firm coherent conglomerate. In still another part of the exposure the same coloration, without cementation, is within fine sand. The other sand and gravel of the exposure ranges in color from maroon (11'm, Chestnut-Brown) to a light-gray (17"b, Cinnamon-Buff) in which iron oxide is unnoticeable. Most of it is colored light grayish-buff (19"i, Isabella Color) by a small amount of iron oxide coloring the light-gray rocks such as limestone and chert. Aside from the coloration by iron oxide mentioned above there are also some lenses generally of coarser material which are colored to various shades by iron oxide. There are also thin seams along some bedding planes and some lenses and thin beds which are colored black. Part of this black coloration is manganese dioxide, but some of it is small fragments of coal and other carbonaceous material. The observed depth of leaching is variable throughout the exposure, which may be due to surface erosion, difference in composition of the gravel, a layer of non-calcareous sand overlying the gravel, or any combination of these. Being located along the valley, some of the surface gravel would be removed as the valley was developed, bringing the unleached material closer to the surface at that point. This can be observed in certain places. Within this exposure there are variations in lithology, certain parts containing a high percentage of carbonates and others having only a small amount. The gravel is overlain by a layer of non-calcareous sand throughout most of the exposure. It is absent in some places but in some it attains a maximum thickness of 8 feet. In other exposures similar to this, sand of this type has been observed which contained practically no carbonates at the time of deposition and thus would be readily leached or appear leached. With all of these variables present the observed depth of leaching cannot represent the true depth to which the carbonates would be removed from normal gravel of this age. In that part of the exposure where conditions seem most nearly normal the carbonates occur within 7 feet of the surface. Weathering has disintegrated many of the crystalline rocks so that they crumble easily and the gray shale falls to pieces soon after exposure to the atmosphere. Only a small amount of the gravel is in horizontal beds, most of it being in beds which dip in any direction at angles below 50 degrees. Lenses and pockets of coarser or finer material are quite common, and the general structure of the entire exposure is irregular and complex. No boulders larger than 30 centimeters in diameter were observed. Except for the few boulders, most

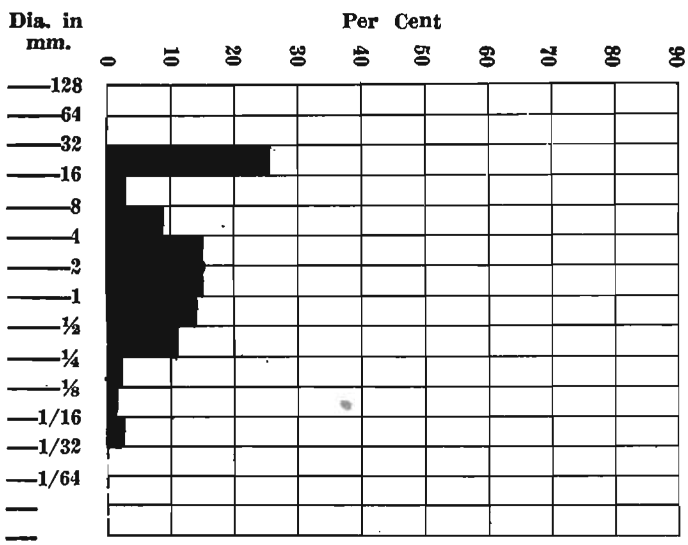


FIG. 25. — Graph showing mechanical analysis of Illinoian gravel.

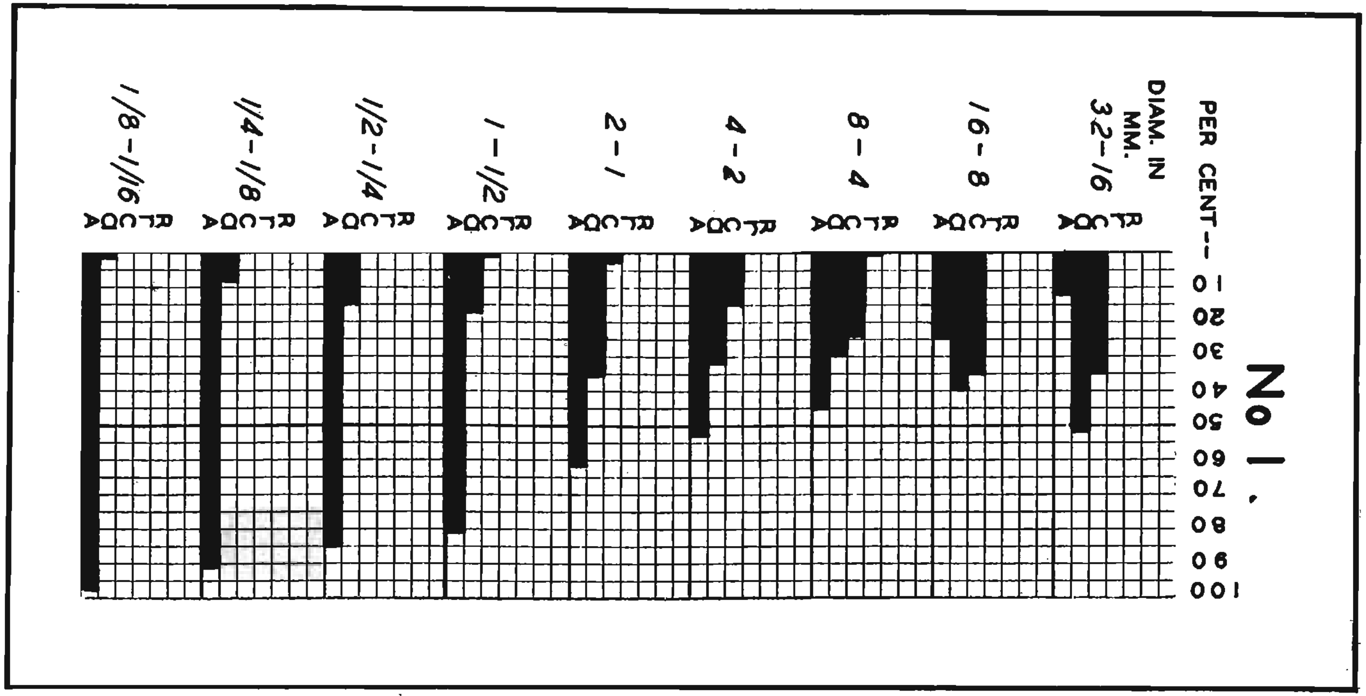


FIG. 26. — Graphs showing shape analyses of each size grade of gravel between 1/16 and 32 millimeters in diameter of Illinoian gravel. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

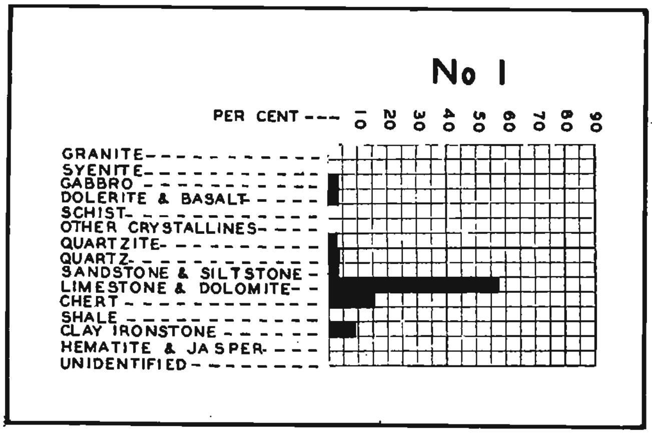


FIG. 27. — Graph showing lithology of pebbles between 16 and 32 millimeters in diameter taken from the Illinoian gravel.

of the gravel is smaller than 5 centimeters in diameter. Lenses, pockets, and irregular masses of sand, silt, or coarser gravel are abundant throughout the exposure. A mechanical separation of a sample of average material is shown in No. 1 of figure 25. The shape of each of the different size grades between 1/16 and 32 millimeters in diameter is shown in No. 1 of figure 26. An analysis of the lithology of the pebbles between 16 and 32 millimeters in diameter is shown in No. 1 of figure 27.

Relations of the Illinoian Upland Gravel:

The top of the gravel is at the same elevation as the surface of the Illinoian gumbotil in this area, 640 feet above sea level.

The gravel has a maximum exposed thickness of 35 feet. It overlies the irregular depositional surface of the unaltered till which in several places extends into the gravel as mound-like masses. The relief of this till surface within the gravel is more than 15 feet.

The top of the gravel, like the base, is very irregular. Throughout most of the exposure the gravel is covered by a layer of laminated sand which has a maximum thickness of 8 feet. In most places it is sharply set off from the underlying gravel, but at one location the two are interstratified and closely related. The sand in turn is overlain by dark-buff, non-calcareous loess which becomes more sandy in the lower few inches where it grades into the underlying sand. It has a maximum thickness of 8 feet in the exposure but must thicken toward the west to form the 15 feet of relief between the top of the gravel and the upland. In one part of the exposure gumboized till is more or less interbedded with the upper 2 feet of gravel.

Age of the Illinoian Upland Gravel:

This irregular mass of gravel within the Illinoian till must have been deposited during the melting of the glacier. The fresh unaltered till below shows that some of the till was deposited before the gravel deposition began. The till that is slightly interbedded with the gravel just below the overburden represents till deposition during the last stages of gravel deposition. All of the evidence suggests that the gravel was deposited simultaneously with the melting of the glacier and deposition of the Illinoian till.

Lake Calvin Basin:

The Illinoian glacier entered Iowa from the east, crossing the present site of the Mississippi river and forcing the river to take a channel along the west margin of the ice. The invasion of the ice not only affected the major stream but also blocked the lower parts of several of the tributaries, such as the Iowa and Cedar rivers, forming lakes in their valleys. These lakes found outlets by flowing over the lowest points in the interstream divides. Probably several lakes were formed at this time, but all except one apparently were short-lived. That one, its areal extent shown in figure 24, has been called Lake Calvin.

Lake Calvin was formed in the valleys of the Iowa and Cedar rivers. These two streams flow from the area of the Iowan drift south and eastward across the Kansan drift. They unite at the edge of the Illinoian drift plain, and from there flow southeastward across the Illinoian drift plain to the Mississippi river.

Three stages in the history of the Iowa and Cedar valleys are significant in the present discussion. The first stage is that during which the Iowa and Cedar valleys were developed. The second stage is that during which the waters of the valleys were ponded by the Illinoian glacier to form Lake Calvin. The third stage records the Iowan glaciation and its influence on the lake basin and the river valleys.

The first stage in this history has been worked out by Leighton for the Iowa river valley,[33] and by Norton for the Cedar river valley.[34] Leighton dates the cutting of the Iowa river valley and its major tributaries of this region as post-Kansan, while Norton states that the wide (bedrock) valleys of the Cedar are at least pre-Kansan in age and may, perhaps, be even pre-glacial.

Lake Calvin, which existed during the second stage of the history, covered the area shown in figure 24. The streams and water from the melting glacier carried sediments that formed typical lacustrine deposits in the lake. Bluffs were formed by the waves sapping the shore; deltas were built by detrital material brought in by the streams; and the finer material from all sources settled in the more quiet waters of the lake to build up its bed. After the lake was drained, these features persisted as marks of the former occupation of this area by lake waters.

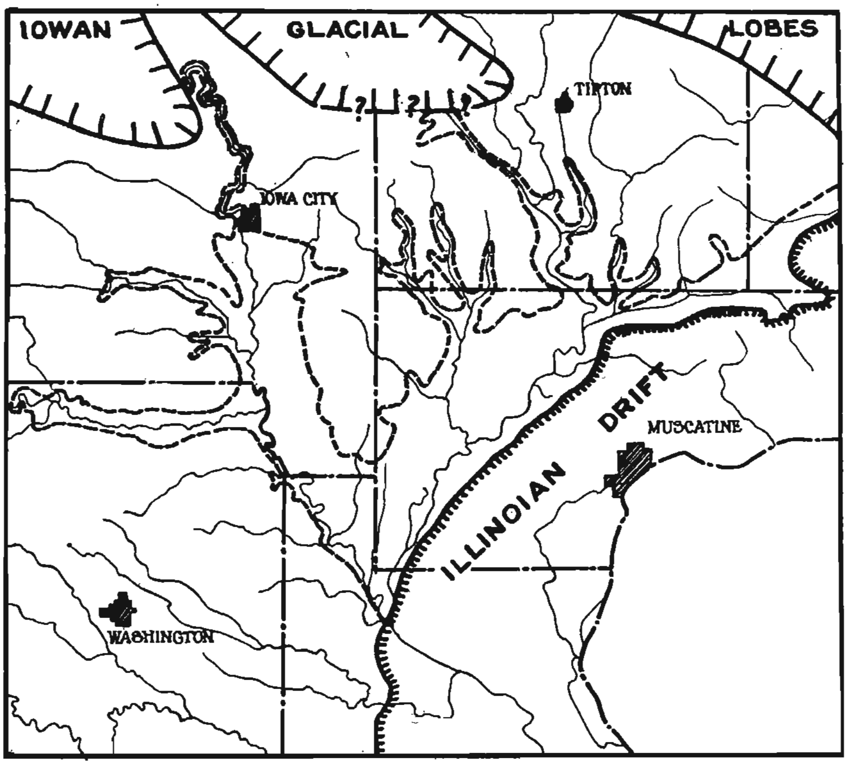


FIG. 28. — Sketch map of the Lake Calvin area showing the drainage during the time of the Iowan glaciation.

33 Leighton, M. M., The Pleistocene History of Iowa River Valley, North and West of Iowa City, in Johnson County: Iowa Geol. Survey, Vol. XXV, pp. 103-181, 1916.
34 Norton, W. H., Geology of Cedar County: Iowa Geol. Survey, Vol. XI, p. 291, 1901.

The third and last stage in the history of this lake area began shortly after Lake Calvin was drained. New conditions created by the advent of the Iowan ice sheet brought about the last stage in the history of the lake area. Figure 28 shows drainage relationships which existed during the third stage.

The drainage lines which crossed the lake floor after is was drained cut their valleys into the lacustrine deposits that then formed terraces along the sides of the streams. The waters from the melting Iowan ice that flowed down the valleys of the Iowa and Cedar rivers were loaded with glacial debris. Much of this material was deposited in the valleys along with reworked material from the eroded lake beds. After the Iowan glacier had retreated and the volume of water decreased to normal, the streams intrenched themselves in these valley deposits which now stand as terraces of sand and gravel above the present floodplains.

The western or Iowa-river arm of the lake basin is about 28 miles long and over this distance has an average width of 4.4 miles. The eastern or Cedar-river arm of the lake basin is about 24 miles long and has an average width of 5.5 miles. Tributary valleys which show that they were in existence and became a part of Lake Calvin during Centralian time are: English River, which shows lake influence for a distance of 15 miles up its valley, and half a mile wide; Old Mans Creek, which has lake deposits for 10 miles along a valley somewhat over a mile wide; and Wilton valley, which shows lake influence for 8.5 miles above Moscow over a floor which is a mile to two miles wide.[35]

The present surface of the bottom of the lake basin is an extensive lowland having a more or less monotonous plain topography with but little relief. It slopes at the rate of about 2 1/2 to 3 feet per mile from the northern to the southern extremities. It includes the terraces shown

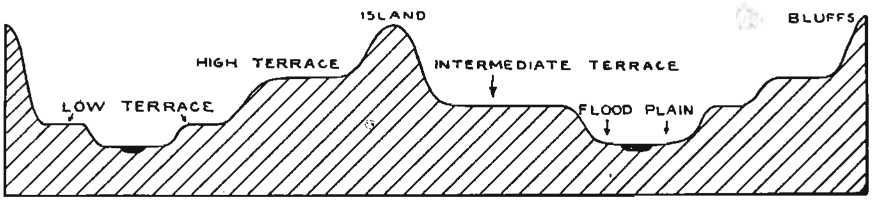


Fig. 29 — Generalized profile of the Lake Calvin basin. (Section by Schoewe.)

35 Schoewe, Walter H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, p. 109, 1924.

diagrammatically in figure 29, which have been described in general by Schoewe [36] in the following manner:

"At least three sets of terraces, a high set, an intermediate set, and a lower one, occur in the Lake Calvin basin. Of these, the intermediate terrace, designated by Udden in his Muscatine county report as the West Liberty plain, is the most extensive and continuous. It comprises practically the entire higher lowland areas in Muscatine county and extends southward as far as Columbus Junction, Louisa county, occupying the higher land area in the triangle made by the junction of Iowa and Cedar rivers.

"The uppermost or highest terrace is confined principally to the Iowa river arm of the lake basin. It forms the higher of the two terraces following the river southward from Iowa City to a point about one and one-quarter miles north of Gladwin in Louisa county. Except for several small remnants on the west side of the river, the terrace is continuous and is limited to the east side of the stream. Terraces presumably corresponding to this upper one are present in Mud Creek valley opposite Wilton Junction and on the higher land bordering the various branches of Wapsinonoc creek north and northwest of West Liberty.

"The lower terrace is restricted to the narrow river-like extensions and to the western branch of the 'V' of the lake basin. This terrace, with one exception, is not continuous but occurs in narrow linear remnants south of Iowa City and as 'mere remnants at the bends of the stream' north of Iowa City and possibly north of Moscow along Cedar river."

He further states, on page 147:

"The higher terrace rises distinctly above the lower one to the west, forming a very sharp and straight escarpment, which on the average is thirty feet high. Near Iowa City it lies sixty feet above Iowa river, while it is fifty feet high in the vicinity of Hills and thirty-two feet high in section 16, Oakland township, Louisa county. It has an elevation of 680 feet above sea level in the vicinity of Iowa City but to the south it is lower, reaching a height of 670 feet near Hills, six to seven miles below Iowa City, and 660 feet two miles south of River Junction. In the lower two tiers of sections in Fremont township, Johnson county, the plain is again somewhat higher, approximating an elevation of 680 feet above sea level. From the elevations mentioned, it is apparent that the surface of the terrace has a much gentler slope — one and four-tenths feet per mile — than the intermediate terrace in Muscatine county."

He describes the intermediate terrace as forming most of the low-

36 *Ibid.*, p. 133.

land of Muscatine and Louisa counties, designated by Udden as the West Liberty plain, but concludes that part of this plain includes some of the higher terrace. The intermediate terrace stands from 20 to 40 feet above the Cedar river, along which it forms an extensive plain.

The lower terrace, confined to the Iowa river valley and its tributaries, occurs as discontinuous remnants about 20 feet above the stream and 40 feet below the high terrace.

Schoewe describes the high and intermediate terraces as lacustrine deposits of the same age and origin, which are higher in the Iowa-river arm because of the greater amount of sediment introduced in relation to the size of the valley, which fills it to a higher level than the Cedar-river arm. The lower terrace is fluvial gravel deposited by the streams flowing from the melting Iowan glacier.

The materials of the high and intermediate terraces are distinctly different from those of the lower terrace. Whereas the two upper terraces are lacustrine in origin, the lower one is glacio-fluvial. In the following discussion Schoewe gives a general description of the materials of the high and intermediate terraces.[37]

"The finding of horizontally laminated clays or silts is positive evidence of quiet water sedimentation and may be taken in most cases as indicating deep water deposits and lacustrine sediments. In general, it may be stated that the materials of the high and intermediate terraces are of low textural range and are finely stratified. Laminated silts or clays, however, are practically limited to the valley of Mud creek . . . As was mentioned in Chapter V under the discussion of the materials and structure of the Wilton Valley terrace, the eastern half of the valley shows a predominance of laminated silts and clays whereas in the west end fine stratified sands are more common. There can be no doubt that the deposits such as are represented by the typical section of terrace materials as given on page 159 (see figure 30) were laid down under quiet water conditions. Practically thirty-four feet of laminated silt or clay is exposed in the type outcrop. Pebbles are entirely lacking and the stratification is horizontal and undisturbed except for a few minor wavy undulations. Other laminated deposits may be seen in the high terrace two and one-half miles east of Hills. . . . Similar sediments are exposed in the intermediate terrace in section 8, Goshen township, Muscatine county. The exposed thickness of these deposits range from seven to twenty feet."

Schoewe describes the material of the lower terrace as follows:[38]

37 *Ibid.*, pp. 181-182.
38 *Ibid.*, pp. 162-163

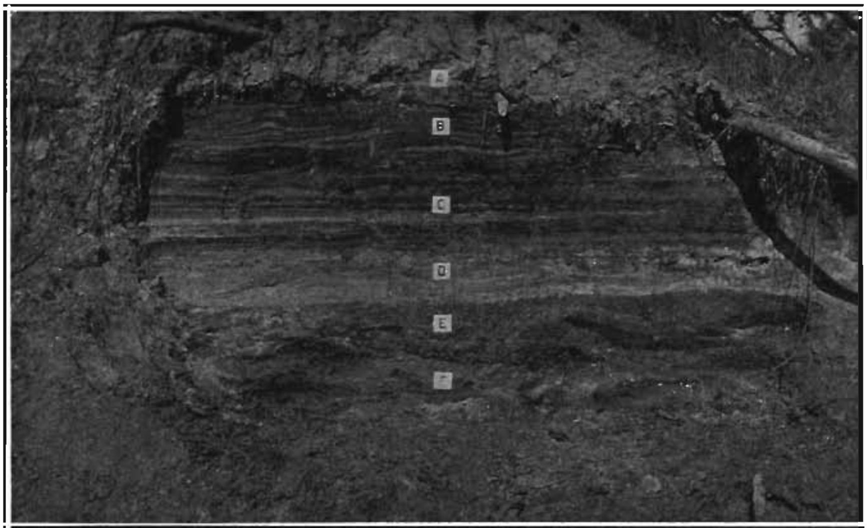


FIG. 30. — View showing typical deposits in the western half of the Wilton Valley terrace, section 11, Moscow township, Muscatine county. (Photo by Schoewe)

"In contrast with the deposits seen in the high and intermediate terraces, the materials of the low terrace are coarser, contain more gravel layers, have a higher textural range and consist predominantly of sands with extremely little silt or clay. In structure there is also a difference. Whereas the high and intermediate terraces contain thinly and horizontally bedded deposits with minor cross-bedding, the prevailing type of structure of the low terrace is well developed cross-bedding and pocket-and-lens stratification."

Detailed descriptions of the materials of each exposure studied are given in his report.[39]

The long duration of Lake Calvin, from the time the streams were dammed by the Illinoian glacier until almost the time of the Iowan ice invasion, has been determined on the basis of the Illinoian gumbotil, the straight line of contact between the high and low terraces along the Iowa river, and the great amount of sediment in the lake basin. Each of these has been discussed by Schoewe.[40]

"It is obvious, if the present view concerning the origin of the gumbotil is correct, that Lake Calvin could not have been drained by way of the Iowa-Cedar river valley shortly after the ice had retreated, since outcrops of Illinoian gumbotil appear on both valley walls of the Iowa-Cedar and Mis-

39 *Ibid.*, pp. 133-168.
40 *Ibid.*, pp. 209-210.

sissippi river valleys. Hence, to say the least, drainage of the lake by this route is post-Illinoian-gumbotil in age. A long-lived Lake Calvin is in accord with the theory of the formation of the Illinoian gumbotil as the levels of the lake and of the gumbotil as they are shown at Columbus Junction were not separated by more than ten to twenty feet, a difference in height which would not give rise to pronounced erosion. Another factor supporting a long existence for Lake Calvin with an outlet south of Columbus Junction and a sudden draining of the lake by way of the Iowa-Cedar valley is the straight line of contact between the high and low terraces in the Iowa river arm of the lake basin. At places where the low terrace is missing, the escarpment of the high terrace is sinuous due to the meandering of Iowa river. At other places, however, where the low terrace lies between the high terrace and the flood plain of the river, the line of contact between the two terraces is unusually straight. This suggests to the writer that the stream which eroded into the high terrace was not meandering and that the formation of the terrace was suddenly halted by the building up of another flood plain which was subsequently cut away to form the low terrace. Therefore, the writer believes that Lake Calvin existed almost to the coming of the Iowan glacier, that the lake was drained in a comparatively short time, and that the down cutting of the lake bed to form the high terrace was shortly interrupted by the aggrading of the valley. The change from an eroding to an aggrading stream was the result of overloading of the stream with sediment received from the melting Iowan ice sheet to the north. As soon as the glacier had retreated from the region, the stream, no longer receiving an unusual amount of sediment, found itself above grade and consequently began to remove the deposited material, producing thus the low terrace, the destruction of which is still in progress."

The Loveland Formation

The Loveland formation includes loess, silt, sand, and gravel which were deposited during the Loveland interval. This formation rests upon the eroded surface of the Kansan gumbotil plain and is overlain by Wisconsin (Iowan, Peorian, and Mankato) deposits. The Loveland interval therefore began not earlier than late Yarmouth time and ended not later than the earliest deposition of the Eldoran epoch, the Iowan.

The type section of this formation is at Loveland, Harrison county. Here Shimek[41] gave the name to a deposit which is a "heavy, compact, reddish (especially on exposure to the air) or sometimes yellowish

41 Shimek, B., Aftonian Sands and Gravels in Western Iowa: Bull. Geol. Soc. of America, Vol. 20, footnote, p. 405, 1909.

silt which when dry is hard with a tendency to break into blocks like a joint clay and when wet becomes very tough and sticky, and hence is sometimes called a gumbo." Although the formation originally included only loess and silt, later studies within the type area and over the rest of the state reveal that the Loveland deposits also include sand and gravel.

The Distribution of the Loveland Gravel:

The Loveland formation has been traced throughout all of the state except that covered by the Mankato drift. No doubt it was also deposited there as in other parts of the state but is concealed by the thick, undissected drift sheet.

Regardless of the wide distribution of the Loveland formation, the differentiated exposures of sand and gravel are confined largely to several valleys in the western and southern parts of the state as shown in figure 31. Since these valleys lie wholly within the loess mantled Kansan drift area, the only possible source of the sand and gravel is the erosion of the Kansan drift, Nebraskan drift, or bedrock. Other valleys within this same area the heads of which extend into the Mankato and Iowan drift areas contain extensive terraces of sand and gravel deposited by the waters from the melting Mankato and Iowan ice fronts. Loveland sand and gravel were probably deposited in all of these valleys which were formed at the same time and under the same erosional conditions. However, those valleys the heads of which extended into the Iowan and Mankato drift areas received later deposition from the melting glaciers. In some places Loveland deposits were probably deeply buried, in others removed, and in still others reworked and incorporated in the younger deposits. During the Loveland interval the amount and rate of erosion was greater in northwestern Iowa than in other parts of the state. Consequently, it is not surprising to find within this area most of the Loveland sand and gravel, which is directly related to this erosion.

The Characteristics of the Loveland Gravel

General Characteristics:

The Loveland sand and gravel can be studied best in northwestern Iowa, where they were deposited in the valleys developed during the Loveland interval. The subsequent stream erosion has cut through

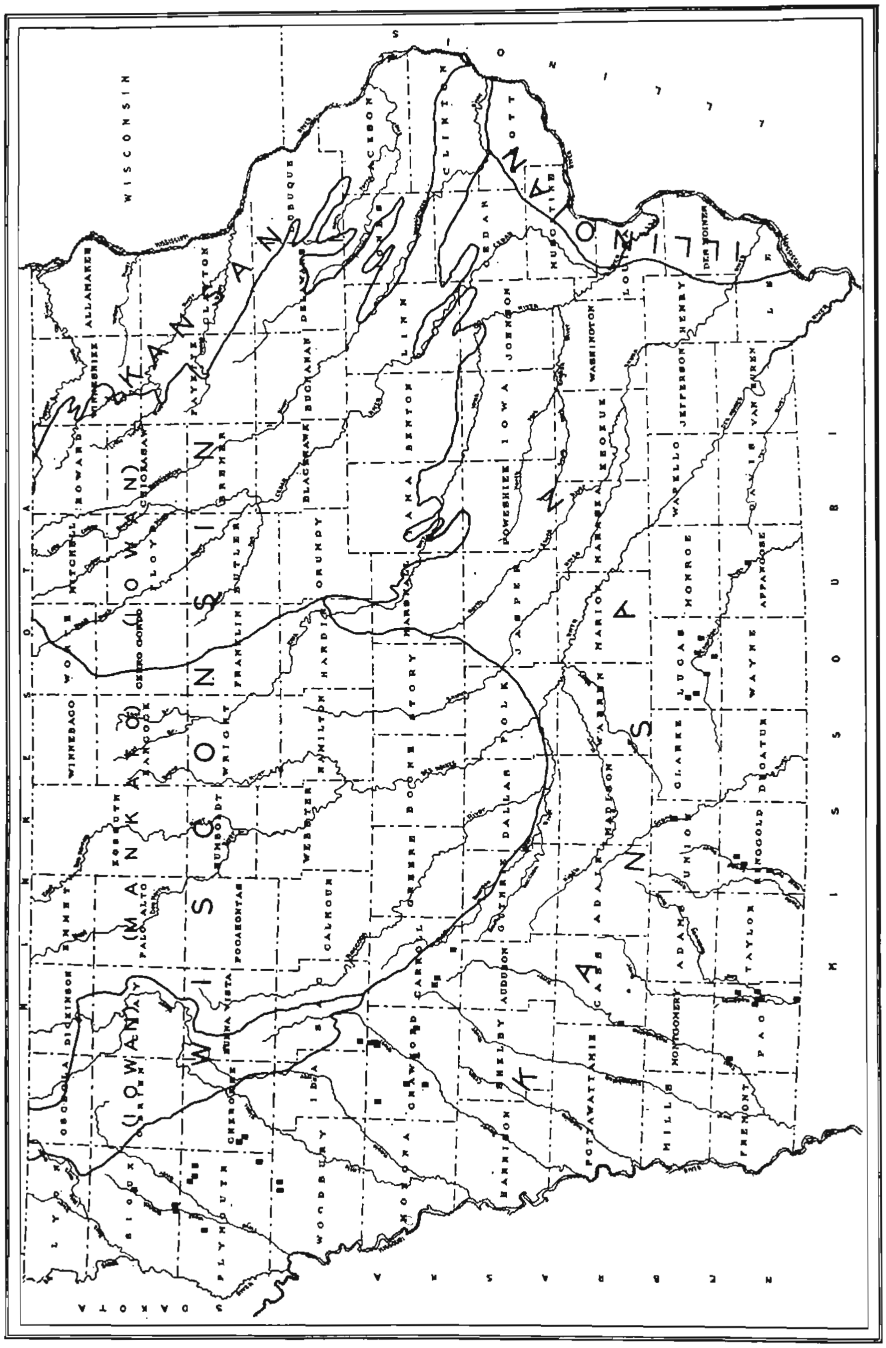


FIG. 31. — The squares show the locations of the Loveland gravel exposures in Iowa.

them, leaving the remaining parts as terraces which vary in height above the level of the present stream. The sand and gravel deposits are well exposed and sometimes show their relations to the overlying and underlying materials.

In southern Iowa, Loveland sand and fine gravel are exposed along several valleys. Most of these exposures are at approximately the present stream level, some are a few feet higher, and others can be studied only by use of an auger. Likewise, along a single stream they may be exposed at one location while a short distance in either direction the stream will be flowing on the alluvium or silt which overlies them.

Since the characteristics of the Loveland gravel of northwestern Iowa are so different from those of the Loveland gravel of southern Iowa, it will be necessary to give a general description of each. The basis for the physical differences between these materials from the separated areas will be given in the discussion of their origin.

The Loveland gravel deposits are exposed within the eroded Kansan drift region which is mantled by loess. They are underlain by yellowish oxidized and unleached Kansan till, or possibly some older formation, and overlain by loess which is closely related in age to the Iowan member of the Eldoran epoch. There is no distinct weathered zone, representing a long time interval, either between the erosion of the Kansan valleys and the deposition of the gravel or between the deposition of the gravel and that of the overlying loess. In some of the exposures all of the above-stated relations are visible, but in most of them only the gravel and overlying loess are exposed.

After an extensive study of the Loveland deposits of northwestern Iowa, Carman makes the following statement with regard to the gravels:[42]

"Most of the valley gravels appear to have originated within the Iowan drift region apparently as outwash from the Iowan ice sheet. This material was gathered into the valleys of the Iowan area and some of it was deposited there. Some of it was carried on southwest down the valleys into the Kansan region and deposited. This will account for most of the valley gravels of the Kansan region, but not for all of them. The gravels of certain valleys of the Kansan region could not possibly have come from the Iowan ice sheet as here interpreted and mapped. In fact, it would prob-

42 Carman, J. Ernest, Further Studies of the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, p. 137, 1929.

ably be necessary to extend the Iowan over all of northwestern Iowa, at least as far south as Crawford and Carroll counties, to make such an origin possible for all the gravels. These gravels must, therefore, have originated in the Kansan region. It is not possible to distinguish the gravels of Iowan age from those that originated in the Kansan region so alike are they in their general characteristics. Further, in both regions they rest on unleached till and are overlain by loess."

The Loveland gravel deposits in northwestern Iowa generally appear fresh with very little, if any, oxidation of the iron compounds. In some of the exposures the gravel is gray and only slightly oxidized but in some others it is colored buff (17" 'd, Vinaceous-Buff) like that of the Peorian loess. No exposure was observed in which the iron oxide colored the gravel darker than buff or cemented either the mass or separate beds into a conglomerate. The only sections showing leaching within the gravel are those in which the overlying loess is thin and the post loess leaching has removed the carbonates from the loess and the upper few inches of the underlying gravel. In accordance with the lack of oxidation and leaching very few of the igneous rocks, commonly in a weathered condition in the older gravel deposits, are disintegrated.

Most of the material is stratified in horizontal beds between 6 and 12 inches thick. Within these beds cross-bedding and lens structures are common, most of which dip in the general direction in which the present stream flows. The sorting is good. In some of the exposures the material is well sorted except for a few pebbles, cobbles, or boulders scattered through the beds of finer material and unrelated to the general stratification. In other exposures the gravel is poorly sorted and there is a wide size range, from sand to cobbles, all within single beds. The deposits show a wide size range both within separate exposures and in the group as a whole. Some exposures are almost entirely sand, while in others there is considerable gravel as coarse as 3 to 5 centimeters in diameter. Within separate exposures there is sometimes fine sand, silt, or loesslike material interstratified with the coarser gravel, or the opposite extreme, an abundance of cobbles and occasionally boulders as large as 60 centimeters in diameter scattered through the finer material. In general the sizes of this material are comparable to those of Iowan terrace gravel deposits within this area. The percentage of each of the different size grades as determined by mechanical analyses is given graphically in figure 32, each graph representing a

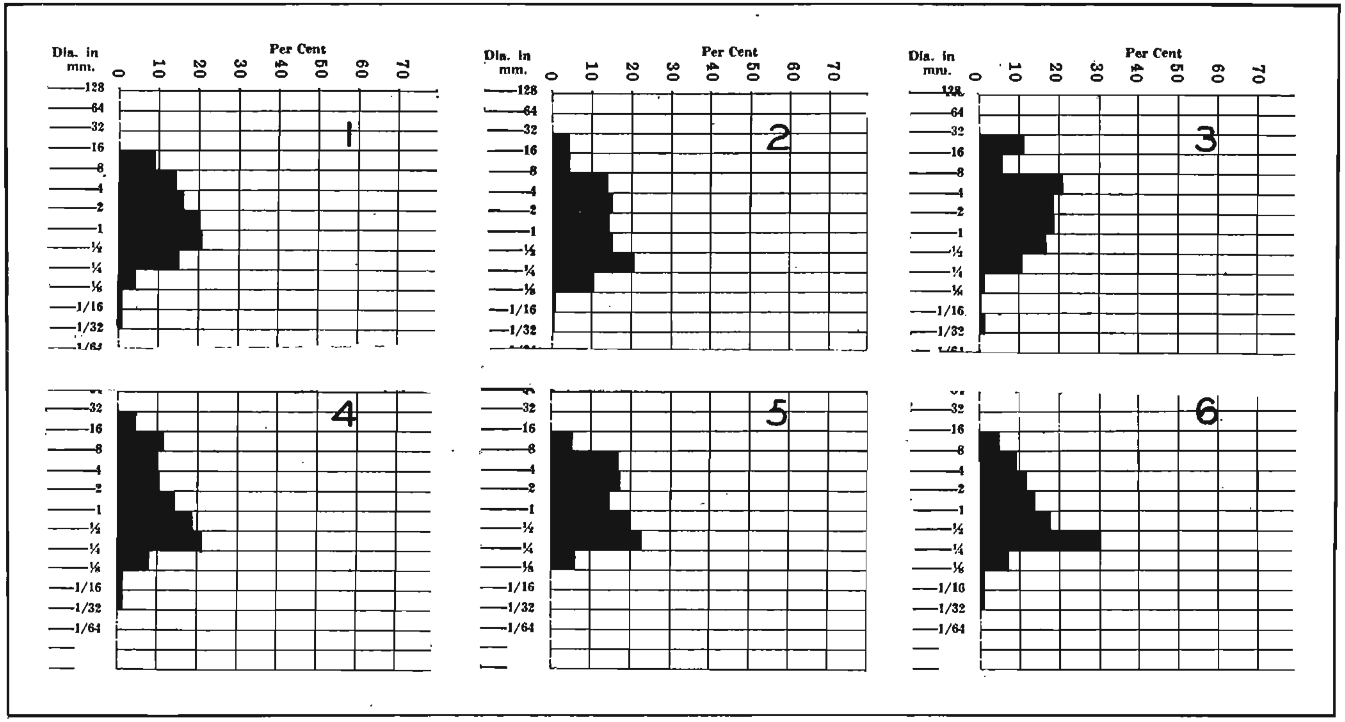


Fig. 32. — Graphs showing mechanical analyses of Loveland gravel. The numbers of this figure correspond with those of figures 33 and 34.

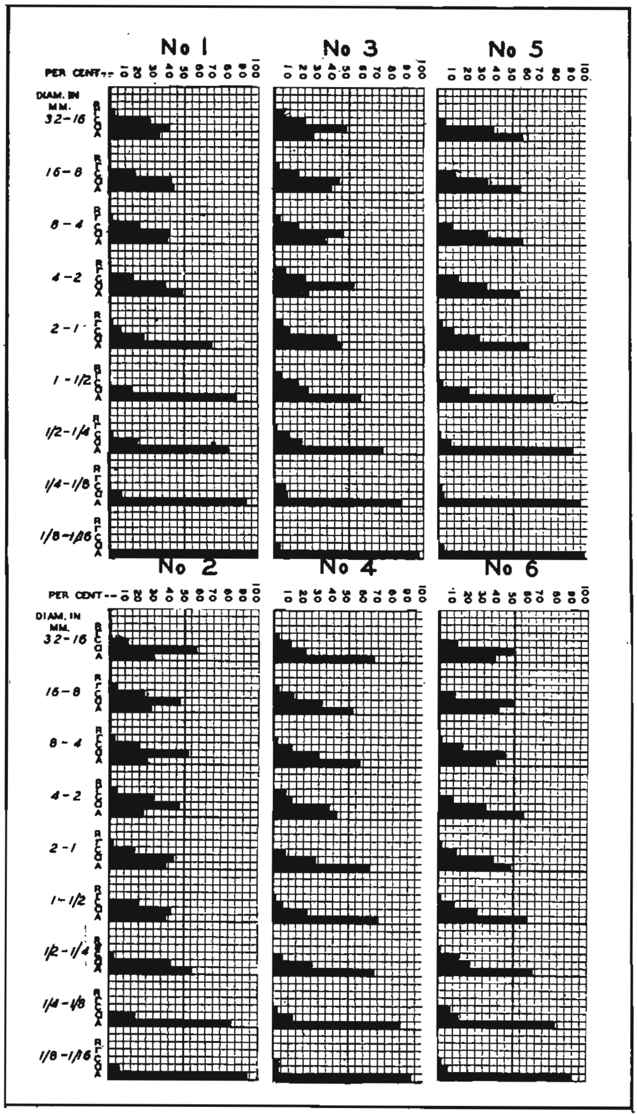


FIG. 33. — Graphs showing shape analyses of each size grade between 1/16 and 32 millimeters in diameter of the Loveland gravel. The numbers of these analyses correspond to the numbers of figures 32 and 34. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

sample which is an average of the exposure from which it was taken. These analyses are from type exposures, some of which will be described separately later in this report; the others are included only for comparison. The shape analyses of the size grades between 1/16 and

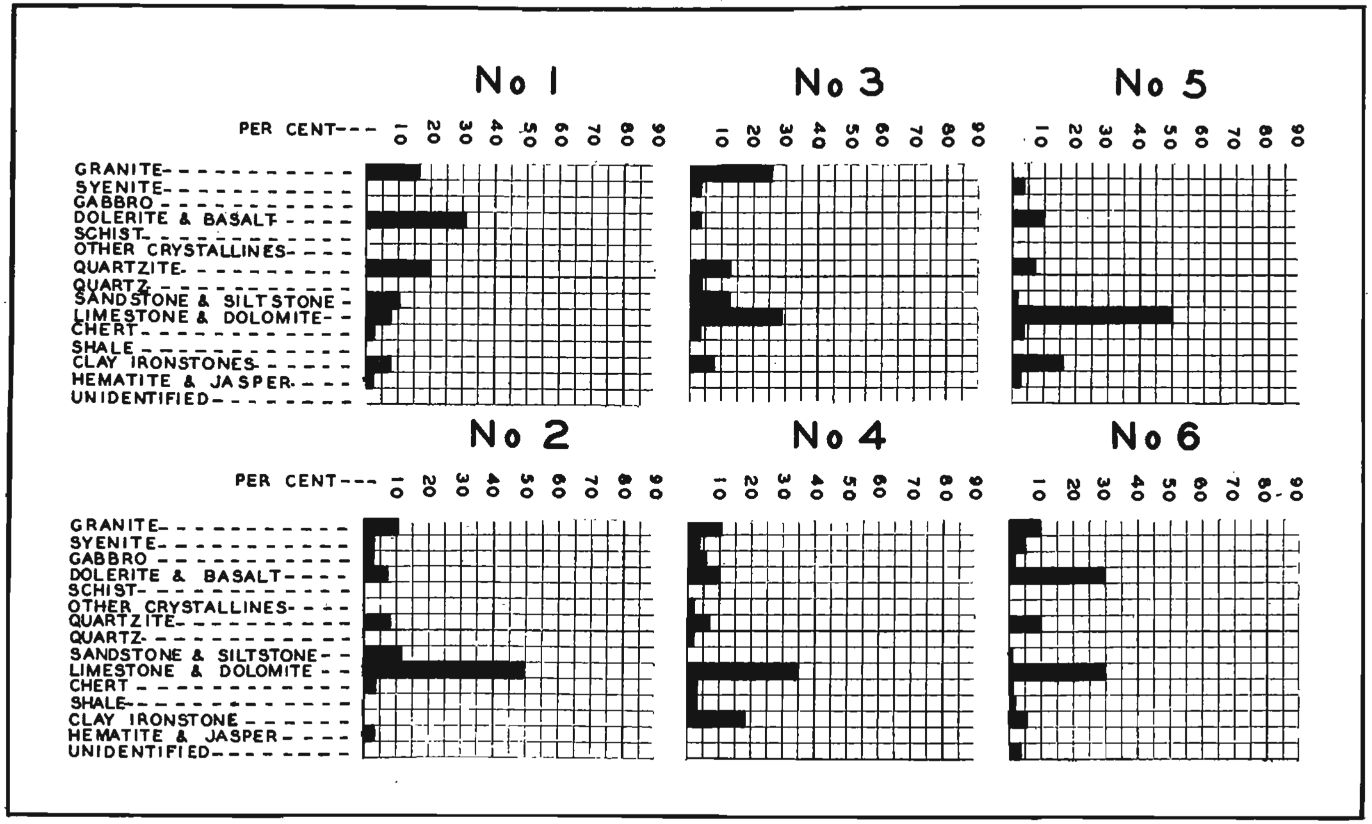


FIG. 34. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond to those of figures 32 and 33.

32 millimeters in diameter are shown in figure 33. The rock content, determined by analyses of the pebbles between 16 and 32 millimeters in diameter, is shown in figure 34.

The Loveland gravel in southern Iowa is generally gray and uncolored by oxidation of iron compounds. However, in a few exposures the iron oxide colors all of the gravel medium-brown (15"i, Sayal-Brown), and in other exposures it colors only thin beds. Carbonates, either primary or secondary, were found in very few exposures. Most of the material is siliceous or fine-grained igneous rock, so there is no distinct evidence of weathering and disintegration. Where studied in place, the material showed good stratification and sorting. Most of the beds were almost horizontal but some dipped downstream. There is no wide size range in any exposure studied nor within the group. In some exposures the material is fine sand with very little coarser than 1 centimeter in diameter; in others it is gravel ranging between 0.5 centimeters and 2 centimeters, but some is as coarse as 4 centimeters in diameter. No cobbles or boulders were found in material definitely recognized as Loveland. In some of the exposures there is silty loess-like material which is closely related and in places interbedded with the sand and gravel deposits.

The Loveland materials observed are only along streams, and their relations to other deposits are difficult to determine, for seldom is their upper surface more than 1 foot above the stream level and generally it is in the bed of the stream. In some valleys in which they are not exposed they have been observed at greater depths during bridge construction.

Characteristics of the Exposures of Loveland Gravel:

Loveland gravel is exposed along streams in many places in northwestern and southern Iowa, as shown in figure 31, but from the general descriptions it is evident that there is a striking difference between the deposits of these two parts of the state. They differ not only in general characteristics and relations but also in distribution and abundance. In northwestern Iowa they are especially abundant in several valleys along which they form extensive terrace deposits, now well exposed.

One of the best streams along which to study Loveland gravel is Otter Creek, a tributary to the Boyer river. It heads up in and flows across Kansan drift, emptying into the Boyer river near Deloit. Along this stream Loveland gravel is exposed in several places.

A good exposure of this gravel along Otter creek is in the southwest part of Sac county. It is near the center of the west half of section 26, Wheeler township (T. 86 N., R. 38 W.), about 5 miles south of the southeast corner of Odebolt. Along the east side of the valley a vast amount of gravel has been removed from several pits which extend intermittently for about 1/4 of a mile along the terrace. Only one gravel pit is now in use and available for study. In the other pits most of the gravel and the overlying and underlying material is concealed by slumping. Although these exposures represent a terrace deposit, the thick overlying loess projects the slope of the hillside over them so that no terrace is visible. The top of the gravel is 40 feet above the stream and extends through all of the exposures at the same level. The exposure is 42 feet thick, the upper 20 feet loess and lower 22 feet gravel. Although no till was exposed in the bottom of the pit, it is doubtful whether the gravel extends much deeper for all of the other pits end at about this same depth, and there is no other apparent reason for their not going deeper. The gravel exposed may be divided into two members — the upper member, which is sand 2 1/2 feet thick, and the lower member, which is gravel 19 1/2 feet thick.

The oxidation of the iron compounds has colored all of the gravel light-buff (17'' 'b, Avellaneous), only slightly darker than the overlying loess (17'' 'd, Vinaceous-Buff). The carbonates have been leached from the upper 9 feet of the overlying loess, and in the unleached loess below fossil snails are found. The 2 1/2 feet of sand at the top of the gravel is also non-calcareous, however, being sand, it probably contained no carbonates when deposited. The coarser gravel below, and even where interstratified with the sand, is all unleached. Some of the large igneous rocks, such as granites and schists, were slightly disintegrated by weathering, but within those smaller than 3 centimeters in diameter very little weathering was observed. No secondary concretions of either iron oxide or lime were found. The upper 2 1/2 feet of sand is all finer than 2 millimeters in diameter and about 85 per cent is between 1/16 and 1/2 millimeter in diameter. It is well stratified in indistinct horizontal beds about 2 inches thick which have no cross-bedding. The lower 19 1/2 feet of gravel is almost all smaller than 6 centimeters in diameter except 13 boulders lying in the bottom of the pit, the largest of which is 35 centimeters in diameter. The average gravel is practically all below 16 millimeters in diameter and 70 per cent is between 1/4 and 4 millimeters in diameter. This gravel is well stratified in beds less than 10 inches thick and generally about 3 inches thick which dip southeast at an angle less than 5 degrees. The small amount of cross-bedding, confined to the thicker beds dips in any direction, principally south. A mechanical analysis of an average of the gravel is shown in No. 1 of figure 32. Shape analyses are given in No. 1 of figure 33. The lithology, as determined by a pebble count, is shown in No. 1 of figure 34.

The 20 feet of Peorian loess which is uniform throughout its entire thickness in both color and texture is sharply divided without gradation from the underlying gravel. No contact with older material at the base of the gravel is visible.

About 3 miles farther south along this same stream there is another good exposure of Loveland gravel. It is in the southeast quarter of section 2, Otter Creek township (T. 85 N., R. 39 W.), Crawford county. The upper surface of the gravel is 20 feet above the level of the stream and is overlain by Peorian loess. Where the loess is exposed overlying the gravel, it is only about 3 feet thick. However it probably thickens toward the hills, whose slope extends down over the gravel terrace. The exposed gravel is 12 feet thick but probably extends several feet deeper.

Oxidation of the iron compounds colors the gravel uniformly throughout the section to light-buff (17" 'b, Avellaneous), about the same color as the overlying loess. Both the gravel and the overlying loess are highly calcareous, the loess containing many lime concretions in its lower part. There is very little disintegration of the rocks by weathering except in some of the less-resistant types. The gravel is well stratified in almost horizontal beds generally less than 6 inches thick. Within the thicker beds is some cross-bedding which dips principally toward the southeast. The entire 12 feet of gravel exposed is quite uniform in texture, although some coarser beds and some finer beds are contained within the average gravel. Size, shape, and rock analyses are shown in No. 2 of figures 32, 33, and 34.

The gravel is overlain by 3 feet of buff (17" 'd, Vinaceous-Buff), calcareous loess which contains a few pebbles and many concretions within its lower part. The absence of leaching within the loess is perhaps the result of recent erosion which has removed the leached material. In this pit the base of the gravel was not exposed.

Another exposure of the Loveland gravel along Otter Creek is about 5 miles farther down stream. It is in the northeast quarter of the northwest quarter of section 36, Otter Creek township (T. 85 N., R. 39 W.), Crawford county. Here within a distance of 3/8 of a mile are 3 pits which contain similar material, 2 on the west side and 1 on the east side of the stream. The terrace in which they occur is 50 feet above the stream.

The gravel is colored buff by oxidation, the coloration varying slightly within the exposure according to the different textures of the beds. At the base of the upper 6-foot bed of gravel there are some thin beds colored black by manganese dioxide. The gravel is all calcareous even up to the base of the leached overlying loess. Weathering has disintegrated very little of the material. Upon the basis of texture the exposure can be divided into three members: the upper 6 feet of coarse gravel, the next 5 feet of slightly finer gravel, and sand at the base. The upper 6-foot bed is well stratified but the coarse material makes the stratification less distinct. Within this bed of coarse gravel there is some interstratification of thinner beds of fine sandy gravel. The largest material observed in this upper member is smaller than 10 centimeters in diameter, and 70 per cent of it is between 1/2 and 8 millimeters in diameter. The oxidation colors this bed to a buffy-brown (17'' 'i, Buffy-Brown), and at its base some of the thin layers are colored black by manganese dioxide. The middle 5-foot member is slightly finer than the upper member but represents about the same type of material, differing chiefly from that above by more oxidation of the iron compounds, which colors it darker, (19''i, Isabella Color). At the base, the lowest member of well-stratified fine sand is all smaller than 8 millimeters in diameter and 60 per cent is between 1/8 and 1/2 millimeter in diameter. It is a darker buff (17''i, Tawny-Olive) than either of the overlying gravel beds. A mechanical analysis of the average material from the 2 upper beds is shown graphically in No.3 of figure 32. The shape of different size grades is shown in No. 3 of figure 33. A rock analysis of pebbles is given in No. 3 of figure 34.

In this and the two exposures near by, the gravel is overlain by Peorian loess which is leached; in neither of the sections, however, is the loess more than 2 feet thick.

At several other locations along Otter Creek besides those described, gravel is exposed in the terraces. One large well-developed exposure is in the southeast quarter of section 12, Goodrich township (T. 84 N., R. 39 W.), Crawford county, near where the stream flows into the Boyer river. This exposure is at an elevation of 50 feet above the stream, and the material is similar to that of the exposures just described except that it is finer. In an average sample of this material, about 73 per cent is between 1/4 and 2 millimeters in diameter.

Along Deep Creek there is a distinct terrace from which Loveland gravel has been removed in several places. This stream heads up in the southwest corner of O'Brien county and flows southwest across Sioux and Plymouth counties, joining Willow Creek about 3 miles northeast of Le Mars. Carman[48] has described several exposures between Remsen and Le Mars, and states that gravel has been seen in every section between the two towns.

The gravel is exposed in a terrace 20 feet above the level of the stream in the south central part of section 31, Meadow township (T. 93 N., R. 43 W.), Plymouth county, about 1 mile north of Remsen. The overburden is loesslike and is probably Peorian loess. It is 3 to 4 feet thick and colored to chocolate-brown in the upper 18 inches by oxidation and humus, while in the lower part it is light buff like normal loess. Leaching has removed the carbonates from all of the overburden, but from none of the underlying gravel.

The gravel is colored by oxidation to a light buff (19"i, Isabella Color), throughout all of the 10-foot exposure. None of the gravel is leached and only a few of the rocks show weathering. The material is well stratified, the beds dipping southwest at an angle of about 3 degrees. The strata are thin and never more than 10 inches thick. There are some lens structures and cross-bedding but only within thicker beds. Within this exposure there are several boulders and cobbles which range in size up to 25 centimeters in diameter, although most of them are smaller than 15 centimeters in diameter. A mechanical analysis of an average of the gravel from this pit is shown in No. 4 of figure 32. It shows a relatively even distribution of about 85 per cent of the material between 1/4 and 16 millimeters in diameter. The percentage of rounding is shown in

48 Carman, J. E., Further Studies on Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 147-149, 1929.

No. 4 of figure 33. The rock content, determined from an analysis of pebbles is shown in No. 4 of figure 34. Although only 10 feet of gravel is exposed in this pit, test holes show the gravel to be more than 45 feet thick.

Another exposure of gravel along Deep Creek is about 4 miles farther downstream. It is in the northwest quarter of section 4, Marion township, (T. 92 N., R. 44 W.), Plymouth county, about 1 mile east of Oyens. Here the gravel is exposed in a terrace 25 feet above the level of the stream. It has been removed over a wide area to a maximum depth of 30 feet, although only about 10 feet of the gravel is exposed above the water in the bottom of the pit. The gravel is covered by about 6 feet of loesslike overburden.

The characteristics of the gravel of this exposure are similar to those of the exposure just described and analyses of the size, shape, and lithology of average material are shown in No. 5 of figures 32, 33, and 34.

Three good exposures of Loveland gravel occur along Brushy fork which heads up in west central Carroll county and flows southeast to where it joins the South Raccoon river near Guthrie Center. The entire length of this stream course is within the Kansas drift area, eliminating the possibility of the gravel being outwash from the Mankato or Iowan ice fronts.

The two best exposures are about 8 miles below the head of the stream. They are only a few hundred feet apart and occur in the same terrace. They are in the southeast quarter of section 28 and the northwest quarter of section 34, Roselle township (T. 83 N., R. 35 W.), Carroll county. These exposures are very much alike and will be described together. The terrace in which they occur stands about 15 feet above the level of the stream and is covered by Peorian loess, the surface of which slopes back into the hills.

This Loveland gravel looks fresh, and slight oxidation colors it to a light grayish-buff (17'' 'b, Avellaneous) throughout the entire exposure. It contains limestone pebbles from top to bottom and shows practically no weathering or disintegration of the material. All of the gravel is well stratified, but within the major beds there is considerable cross-bedding and many lenses. None of the gravel observed is larger than 2 centimeters in diameter and very little (about 4 per cent) larger than 1 centimeter in diameter. A mechanical analysis of the average material shows about 70 per cent between 1/2 and 4 millimeters in diameter.

The loess overlying the gravel is leached to a depth of 3 1/2 feet in one exposure while in the other it is unleached to the surface. However, it is possible that there has been erosion on the unleached loess surface. The contact of the base of the gravel was not exposed.

About 6 miles farther down the stream there is another exposure of Loveland gravel similar to the one just described. It is in the central part of section 20, Newton township (T. 82 N., R. 34 W.), Carroll county, in the southwest corner of Dedham.

The gravel of this exposure is colored to a slightly darker-buff (19''i, Isabella Color) than the one just described farther upstream. Leaching has removed the carbonates from the overlying 4 feet of loess and from the upper 6 inches of gravel. Only a few of the rocks show disintegration by weathering. The gravel is well stratified and cross-bedding is common within the major beds. The material of this exposure is coarser and not so uniform in texture as that of the other exposures observed along this stream. Other than a few large boulders in the base of the pit which have a maximum average diameter of about 30 centimeters, nothing observed was larger than 5 centimeters. A mechanical analysis of average gravel shows 50 per cent between 1/4 and 1 millimeter in diameter and only 5 per cent between 8 and 16 millimeters in diameter. A mechanical analysis of the average gravel is given in No. 6 of figure 32. The percentage of rounding is shown in No. 6 of figure 33. A lithologic analysis of pebbles is shown in No. 6 of figure 34.

Loveland silt, sand, and gravel is exposed along several streams in southern Iowa. However, it is deeply buried below younger loess and alluvium, and only in a few places do the present stream valleys cut deep enough to expose this material. Along some of the streams the Loveland materials have been encountered only in excavations below the level of the stream bed.

In the report on the geology of Page county, Calvin[44] described some old loess, silt, and sand deposits but had difficulty in explaining their origin. In the light of present knowledge it is evident that they are of Loveland age. In this report he gave the following descriptions:

"In some instances there are indications of two distinct beds of loess.

44 Calvin, Samuel, Geology of Page County: Iowa Geol. Survey, Vol. XI, pp. 444-447, 1901.

For example, on top of the hill east of the Grabill brickyard, the fresh cut surface showed:

		Feet
4.	Light colored loess, not very ferruginous	6
3.	Yellowish sand, the upper 10 inches clay colored, the lower part showing cross-bedding. The laminae in the cross-bedded portion are inclined toward the east, away from the river valley	2½
2.	Dark colored, ferruginous, weather-stained loess, quite different in appearance from No. 4	5
1.	Very much weathered drift, ferruginous, leached, the cobbles and pebbles much decayed, the whole stained with organic matter; exposed	7

"The two beds of loess are very distinct in color, No. 2 showing signs of much greater age than No. 4. The obliquely bedded sand, No. 3, may probably be of eolian origin. The altitude is 160 feet above the present flood plain of the river, and it is scarcely conceivable that this material could have been deposited by currents of water flowing toward the east."

In this section the old loess is no doubt Loveland loess containing a pocket of gravel. The younger loess is Peorian which overlies the Loveland and other older deposits that were exposed at the time it was deposited.

Calvin also described deposits within the valleys which he was unable to interpret in harmony with conditions of the Pleistocene as then known. They are as follows:

"In nearly all the valleys of Page county there is a formation which in some of its phases resembles loess; but in other of its aspects it is clearly an aqueous deposit. It has evidently been laid down since the valleys reached approximately their present depth. North branch near Clarinda has its channel cut in this material. It is yellowish in color, tough, jointed and obscurely stratified. Unlike loess, it contains occasional pebbles and pockets of sand . . . Above the section described at Braddyville, west of the railway track, there is a body of this clay, 20 feet thick and forming a distinct terrace 50 yards yards or more in width at the top. The hard, enameled scales of the gar pike, Lepidosteus, were found in this bed at Braddyville, the scales retaining their proper relations to each other as if the fish had been buried at the time the silt was forming. Between the point where the scales were found and the railway station, some recent cuttings show beds of stratified sand below the level of the clay. The same yellow silt is found beneath sandy alluvium in the valley of Buchanan creek, east of Braddyville. It is well shown in the bank of the Nishnabotna river west of Essex, where it is overlain by 6 feet of a fine, loess-like silt and 2 or 3 feet of black loam. At the Rankin Brothers' brickyard at Shenandoah, the section of the clay pit shows:

		Feet
3.	Loesslike clay	8
2.	Bluish stratified clay, clearly an aqueous deposit, but flexed more or less as if laid down on an uneven surface	1
1.	Porous, dark, granular clay	7

"Nos. 1 and 3 resemble loess, but No. 2 records a distinct episode between the more recent and a more ancient period of loess formation during which the valley was temporarily flooded.

"The distribution of this deposit is practically universal in all the valleys below a certain level. There has been some valley cutting since it was laid down, but little as compared with what took place beforehand."

At present we recognize an old loess, the Loveland, which contains lenses and pockets of sand and gravel as those Calvin described within this area. Also, recent studies reveal similar deposits at other locations both within this county and in other counties in southern Iowa. Even though Calvin did not recognize the origin and age now accepted for these deposits, he must be credited with accurate descriptions and interpretations of his observations.

In the dredged ditch along the East Nodaway river, in the southwest quarter of section 34, Nebraska township (T. 69 N., R. 36 W.), Page county, about 3 miles east of Clarinda, there is a good section which shows Loveland silt, sand, and gravel. It is:

		Feet
4.	Alluvium, black, silty clay, unstratified, tough and heavy, unleached	10
3.	Loess, gray-brown mottled, unstratified, leached	4
2.	Silt, gray stratified, grades into No. 3, beds thin, laminations at the top, but toward the base the beds become thicker and the material coarser, including sand and some gravel, all leached	3
1.	Gravel, gray, sandy, leached, poorly stratified in relatively horizontal beds; exposed	⅓

In the above section, Nos. 1, 2, and 3 are interpreted as Loveland, and the overlying material, No. 4, as younger alluvium.

In an excavaton in the valley of the West Nodaway in the northwest quarter of section 32, Nodaway township (T. 69 N., R. 36 W.), Page county, a thick bed of gray silt is exposed under the dark-colored alluvium. This section appears to be comparable to the one previously described, the silts representing Loveland valley deposition.

Another exposure similar to the one along the East Nodaway river is along the dredge channel of the West One Hundred and Two river. This is in the northwest quarter of section 10, Mason township (T. 68 N., R. 35 W.), Taylor county. The section is as follows:

	FEET
4. Alluvium, black, heavy, unstratified, leached	12
3. Loess, gray with mottling of iron oxide, leached, tough and heavy; slight gradation into No. 4	9
2. Silt, gray, indistinctly stratified; one bed near the base is fine, almost clay; leached	2½
1. Sand, buff, leached, contains some black claylike material. Below the level of the surface of the stream it is colored grayish-green by the water	1

Numbers 1, 2, and 3 of this section are interpreted as Loveland and No. 4 as recent alluvium. Although no gravel is exposed in this section, the stream flows on gravel less than 1/4 mile away, which suggests that it has cut across a lens of gravel included in the silt and sand.

In Ringgold county, the Loveland is exposed along the dredged channel of Platte River near the center of the south side of section 3, Benton township (T. 68 N., R. 31 W.), about 2 1/2 miles west of Benton. Here the section is as follows:

	FEET
4. Black, silty loam, soil layer	1½
3. Loess, light brownish-buff, and leached; grades into No. 4 through a 6-inch transition zone	8
2. Loess, gray, leached; tough and plastic; looks like an old loess	6
1. Sand, fine-white, leached, contains a few small pebbles; exposed	2

In the above section the numbers 1 and 2 are believed to represent Loveland valley deposits, No. 3 Peorian loess, and No. 4 Peorian loess modified by a soil zone. This section is near the edge of the valley and does not contain alluvium but rather loess like that on adjoining slopes.

Exposures of Loveland deposits, including sand and silt have been observed in several places along stream valleys in Lucas county. One of the best of these exposures is along a branch of White Breast Creek, near the center of section 21, Benton township (T. 71 N., R. 21 W.), about 1/2 mile west of Russell. The section here is as follows:

	FEET
10. Soil filled with roots	2
9. Gray sand and gravel oxidized, brownish and reddish, strongly cemented	3
8. Sandy clay band	½
7. Gravel oxidized, brownish yellow	1¾
6. Clay seam, distinct	1/6
5. White sand	1
4. Yellow sand, pebbly below	1
3. Clay seam	1/6
2. White sand with yellow streaks, oxidized at base	1
1. Yellowish, grayish clay, drift	8

All of the above section is leached of its carbonates and represents

Loveland deposition along the valley. If there is any Peorian loess here it is very thin.

Aside from those described above, there are many other deposits of Loveland silt, sand, and gravel throughout this area, as shown by the locations on figure 34. Although they are not described, they are similar to those described within the same area.

Relations of the Loveland Gravel:

The Loveland formation — consisting of loess, silt, sand, and gravel deposited during the Loveland interval — is widely distributed, having been found in most parts of the state. The loess and silt are the most widely distributed, but sand and gravel occupy some valleys in western and southern Iowa.

The term Loveland was introduced by Shimek [45] in 1909, but has been further defined during more recent years by Kay,[46] who has recognized and described it throughout most of the state. Further descriptions of the formation and its relations have been given by Carman [47] in his most recent report on the Pleistocene geology of northwestern Iowa. The Loveland formation rests upon the eroded surface of the Kansan gumbotil plain. Therefore, the Loveland interval began not earlier than late Yarmouth time, as the gumbotil had been formed and the mature dissection of the drift plain had occurred before the Loveland was laid down. This formation is in many places leached, and some of the materials show alteration beyond the mere removal of the more soluble constituents. A young loess, commonly unleached, overlies the Loveland in most places, indicating that the alteration of the Loveland loess and silt occurred before the deposition of this overlying material. Iowan till overlies the Loveland in other sections. The Peorian loess and Iowan till, closely related in age and resting on the Loveland deposits, show that the Loveland interval preceded their deposition.

The type section of the Loveland was described from Loveland, Iowa, in northwestern Pottawattamie county, where the loess rests upon 11 feet of oxidized and unleached till over bluish-gray un-

45 Shimek, B., Aftonian Sands and Gravels in Western Iowa: Bull. Geol. Soc. of Amreica, Vol. 20, footnote, p. 405, 1909.

46 Kay, G. F., Recent Studies of the Pleistocene in Western Iowa: Bull. Geol. Soc. of America, Vol. 35, pp. 71-73, 1924. Loveland Loess, Post-Illinoian, Pre-Iowan in Age: Science, N. S., Vol. LXVIII, pp. 482-483, 1928. Significance of Post-Illinoian, Pre-Iowan Loess: Science, N. S., Vol. LXX, pp. 259-260, 1929. With Apfel, E. T., The Pre-Illinoian Pleistocene Geology of Iowa: Iowa Geol. Survey, Vol. XXXIV, pp. 277-281, 1929.

47 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 49-52, 1931.

weathered till. Here the Loveland loess is covered with thick buff loess, most of which is Peorian in age. Both loesses are fossiliferous, fossils being more abundant in the Peorian loess than in the Loveland.

Another exposure of Loveland loess is in a railroad cut just east of McPherson station on the Chicago, Burlington and Quincy railroad, in Montgomery county. Here leached Loveland loess more than 20 feet thick is exposed under 25 feet of buff calcareous loess.

From these two sections alone, it is evident that the Loveland loess varies greatly in the amount of alteration, and thus must have been deposited at different times during the interval. Other exposures show differences similar to those just described.

The gravel and sand deposited in the valleys, like the loess and silt deposited on the uplands, show differences in alteration within the different exposures studied.

In the previous descriptions of gravel exposures in northwestern Iowa there is no evidence of a period of weathering between the time of gravel deposition and that of loess deposition. Only where the overlying Peorian loess is thin and all leached is there any leaching in the upper part of the Loveland gravel.

An exposure of gravel along the south side of the valley of East Fork, east of Denison, in Crawford county, shows not only buff calcareous loess overlying calcareous gravel but also interbedding of the two. The entire length of this stream is within the Kansan drift area, so it could not contain Iowan gravel. If this loess is Loveland rather than Peorian, the Peorian loess which is thick within this area is either absent here or cannot be differentiated from the Loveland loess. Besides being closely related to the overlying Peorian loess, the Loveland terraces correspond in elevation with the Iowan and Mankato terraces of this area. The gravel of these terraces, the Loveland and Iowan or possibly Mankato, are similar in most respects but differ slightly in general lithologic content, the Loveland containing a greater percentage of the more resistant kinds of rock.

The overlying silt and loesslike clay are not distinctly separated from the sand and gravel but in some places are interbedded. The non-calcareous condition of these deposits would suggest that they were weathered for a long period of time before the deposition of the Peorian loess. This being true, these Loveland deposits must have been deposited long before those of the Peorian loess and also long before Loveland gravel of northwestern Iowa. However, this difference in the deposits need not all be explained on the basis of time of deposition, because the long period of erosion was far more effective in northwestern Iowa, where it removed all of the gumbotil and leached till from the Kansan, than in southern Iowa, where it merely cut valleys in the gumbotil plain. This not only would allow a greater supply of gravel for the streams of northwestern Iowa but there would also be a greater percentage of gravel derived from the unweathered till.

The Age of the Loveland Gravel:

The age of the Loveland gravel has been discussed along with the relations of the deposits. However, in summary, the following statements might be made: Loveland deposits of loess, silt, sand, and gravel lie upon the eroded surface of the Kansan drift or older deposits, the erosion beginning after the formation of the Kansan gumbotil and during the Yarmouth Age. They are overlain by Iowan till and Peorian loess. These two limits bound the Loveland interval during which these materials were deposited. In previous papers by Kay, listed in footnote No. 46 (p. 116), the age of the deposits has been discussed in detail. It suffices here to state that, on the basis of present evidence, the sand and gravel, like the loess and silt, may have been deposited at any time during the interval, some probably during the late Yarmouth age and others as late as the immediately pre-Iowan. In fact, all evidence is in harmony with the conclusion presented by Carman,[48] that part of the gravels of northwestern Iowa were deposited just before the Peorian loess deposition or approximately at the time of the Iowan glacial advance. However, it is probable that those of southern Iowa were deposited during an earlier part of the interval and that the distant Iowan glacier had little effect upon deposition within these valleys. It is possible that deposits similar and of the same age as those of southern Iowa were also deposited in the valleys of northwestern Iowa, but with the climatic changes accompanying the Iowan glacial advance, more material was introduced and the older deposits were reworked and deposited along with the newly introduced material.

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[48] Carman, J. Ernest, Further Studies of the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, p. 149, 1931.

The Gravels of the Eldoran Series — the Iowan and Mankato Substages

THE IOWAN GRAVELS

As the Iowan glacier melted, it deposited its load on the eroded surface of the Kansan drift and on other surface deposits over which it had advanced. However, the Iowan drift was thin and did not fill the valleys and thus did not level the surface as had the older glacial deposits, but spread over the eroded Kansan surface as a blanket, forming a drift-mantled erosional topography. The water flowing from the melting glacier deposited gravel of two general types: (1) masses within and on the surface of the Iowan till, forming what will be referred to as Iowan upland gravel; and (2) outwash, referred to as Iowan terrace gravel, deposited along unfilled pre-Iowan valleys both inside and beyond the Iowan drift border. These two types of Iowan gravel will be treated separately, since they are of different origin and have different characteristics.

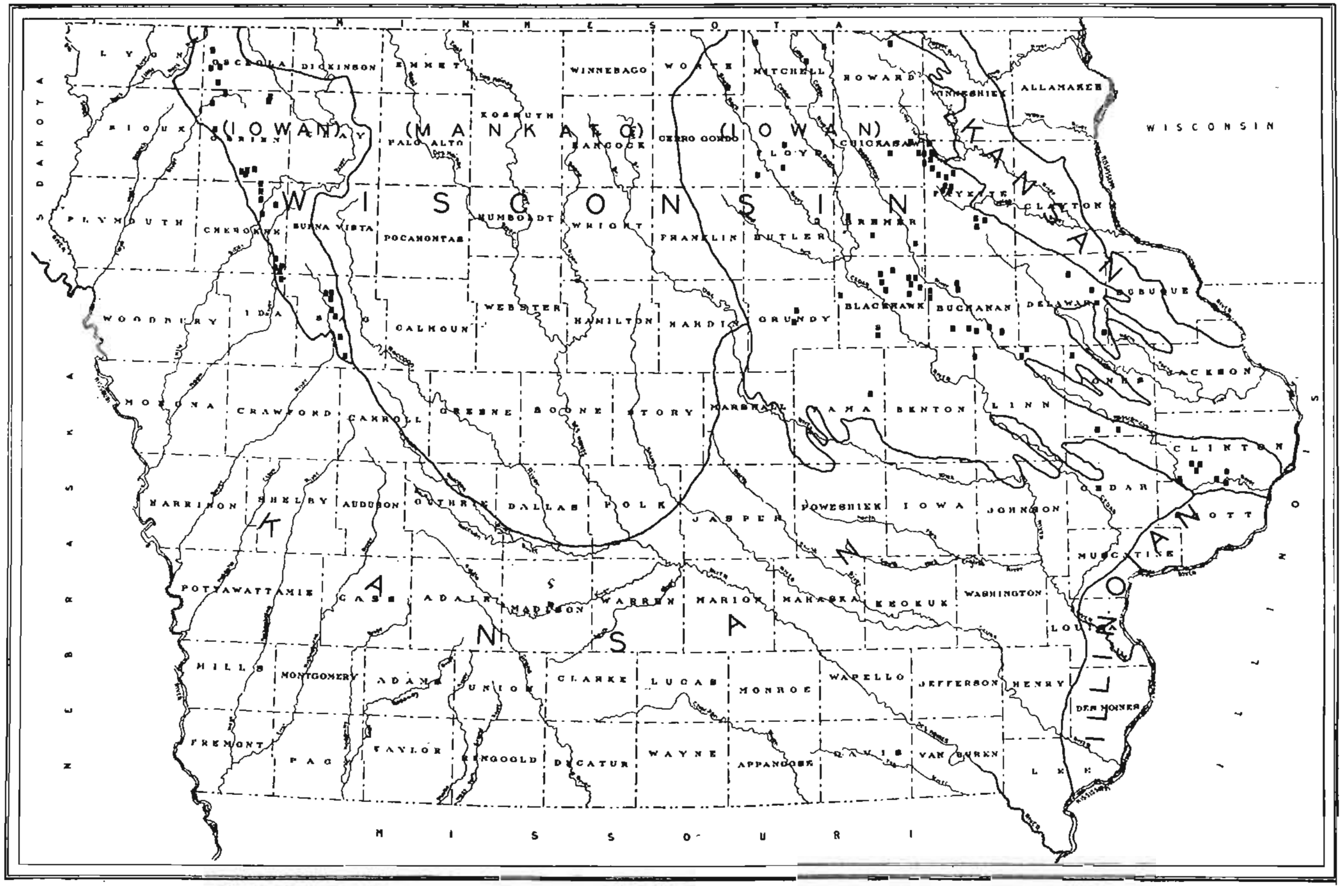
The Iowan gravel deposits have been studied for many years chiefly within northeastern Iowa, and have been described in many reports. However, in the reports published before 1915 and in some since, they have been described and interpreted as Buchanan gravels deposited during the retreat of the Kansan glacier. The two types of deposits were recognized and given the names Upland phase and Valley phase of the Buchanan. In the report on the geology of Howard county, Calvin described the genesis of these deposits which he thought were of Kansan age.[49] Calvin's Valley phase is Iowan terrace gravel, but his Upland phase includes both Iowan upland gravel and Kansan gravel. He failed to differentiate the Iowan upland gravel from the Kansan upland gravel.

THE IOWAN UPLAND GRAVEL

Distribution of the Gravel

The Iowan upland gravel deposits distinctly related to the Iowan till, are unevenly distributed throughout the area covered by the Iowan glacier. They occur within the Iowan drift areas of both northeastern and northwestern Iowa and are distributed as shown in figure 35. Their abundance, characteristics, and accessibility make them ex-

49 Calvin, Samuel, Geology of Howard County: Iowa Geol. Survey, Vol. XIII, pp. 67-68, 1903.



MAP OF IOWA

FIG. 35. — The squares show the locations of Iowan upland gravel exposures in Iowa.

tremely valuable as road surfacing material, for which they have been used extensively. Since there has been very little post-Iowan erosion, good natural exposures are rarely found and the gravel pits from which the deposits have been removed afford many good fresh exposures for study. It is probable that some of the Iowan upland deposits are masses so deeply buried within the Iowan till that they are not available for commercial use. However, the Iowan till is so thin in most places that large masses of gravel could not be buried deeper than a few feet except where the till is covered by thick Peorian loess.

Characteristics of the Gravel

General Characteristics:

The deposition of the Iowan upland gravel is closely related to the retreat of the Iowan glacier and deposition of the Iowan till. The known exposures of the gravel occur at any one of four general positions with respect to the Iowan till: (1) Several exposures show Iowan gravel interbedded with Iowan till. (2) A few are pockets buried within the till. (3) Others are small kamelike knobs or hills which stand above the drift surface, and (4) many of them are pockets of gravel located near the tops of the hills, their upper surface almost at the same level as that of the drift.

The Iowan areas in which the gravel deposits were studied have not been buried by more recent post-Iowan deposits other than the Peorian loess, which was deposited almost immediately following the deposition of the Iowan till; but they have been at the surface and subjected to the processes of weathering during subsequent time.

The Iowan till and Peorian loess combined have been leached of their carbonates to an average depth of 4 to 6 feet, and the iron compounds have been oxidized still deeper. This makes these deposits divisible into three zones: the oxidized and leached at the surface, underlain by the oxidized and unleached, which in turn is underlain by the unaltered material. Weathering has not continued long enough for gumbotil to form, as it has on the older drifts.

During the time that the till and loess were being altered to their present condition, the gravel occupying a like position was undergoing comparable changes.

The leaching within the gravel has removed the carbonates to an average depth of 4 to 6 feet, which is approximately the same as within the till. In a few exposures ground water has deposited calcium carbonate at lower depths in the form of concretions and cement. This cementation is quite variable in respect to the general stratification; sometimes it is within one bed or zone, but more frequently it cements irregular masses which vary in size from a few inches to more than 20 feet in diameter. The cemented gravel forms a firm, friable conglomerate which in extreme cases will fracture across the weaker rocks rather than through the cement surrounding them.

The oxidation of the iron compounds generally colors the complete exposure to a uniform color which ranges from light-buff (15'i, Ochraceous-Tawny) to reddish-brown (11'k, Hazel). However, in some exposures the different beds show extreme variation in color and some entire exposures show almost no coloration by iron oxide. The wide range in color makes it impossible to differentiate Iowan gravel from other gravels on the basis of oxidation. When present, the iron oxide coating the grains and partly filling the interstitial spaces cements the gravel into a compact, weakly coherent mass which stands in exposures with a vertical face, but can be broken easily with slight pressure. Occasionally thin beds are more highly oxidized and form a firm conglomerate which breaks more readily across some of the weaker rocks than does the cement. Thin beds, seldom more than 1 inch thick are sometimes colored black by manganese dioxide which coats the grains. The disintegration of the rocks by weathering — so evident in the Kansan, Nebraskan, and Illinoian gravels — is not as commonly observed in the Iowan deposits.

Most of the deposits are well stratified, generally in horizontal beds. However, they may include many irregularities such as lenses, pockets, cross-bedding, steeply dipping beds, clay-balls, boulders, inclusions of Iowan till, and inclusions of older material such as till, gumbotil, and Loveland loess which were removed from the pre-Iowan surface by the advancing Iowan ice. In places leaching, poor sorting of the material, and oxidation of the iron compounds give the deposits an unstratified appearance. There is a wide size range within the separate exposures and throughout most of these deposits. Most of the material is smaller than 6 centimeters in diameter, but there are many cobbles and boulders distributed through the gravel, some of which have an average diameter of more than 80 centimeters.

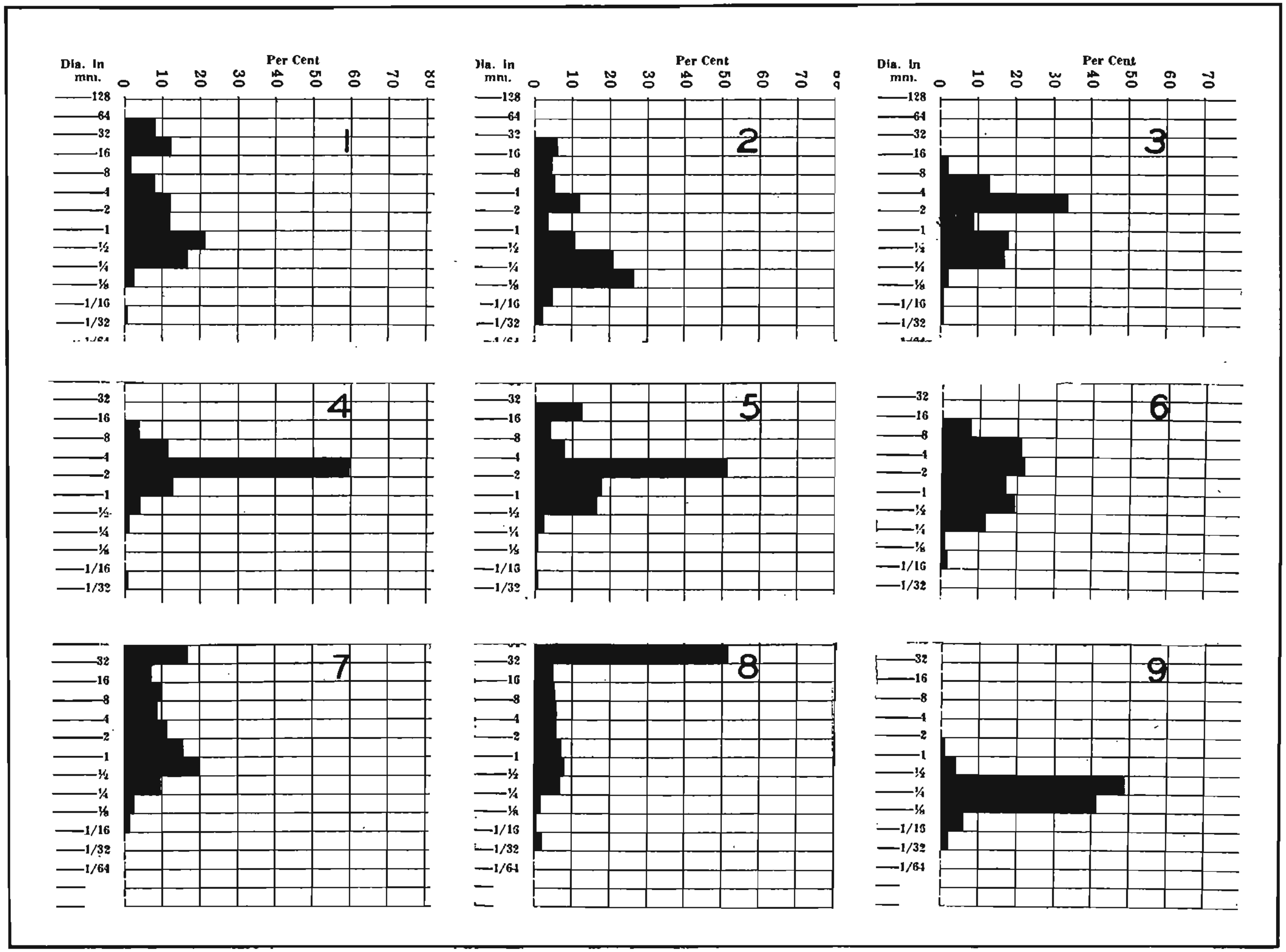


FIG. 36. — Graphs showing mechanical analyses of Iowan upland gravel. The numbers of this figure correspond with those of figures 37 and 38.

The percentage of each different size grade as determined by mechanical analyses of average samples from each exposure is shown in figure 36. The percentage of rounding of each size grade between 1/16 and 32 millimeters in diameter of the above mechanical analyses

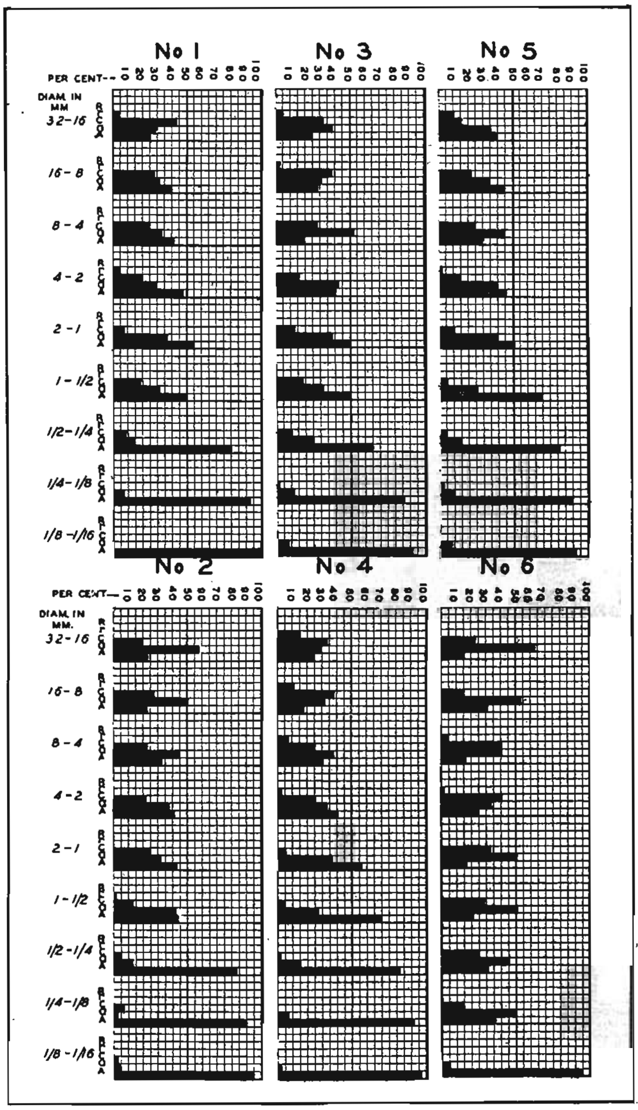


Fig. 37. — Graphs showing shape analyses of each size grade between 1/16 and 32 Millimeters in diameter of the Iowan upland gravel. The numbers of these analyses correspond with those of figures 36 and 38. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

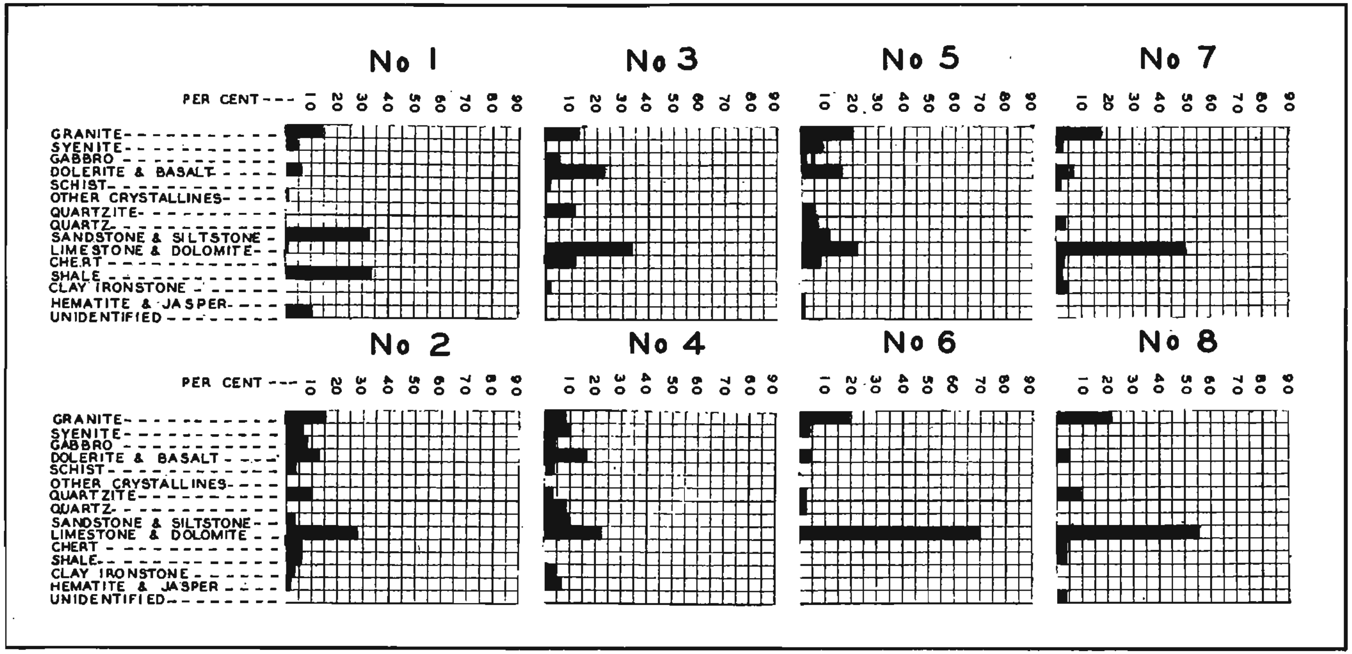


FIG. 38. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond with those of figures 36 and 37.

is shown in figure 37. Rock analyses of pebbles between 16-32 millimeters in diameter are given in figure 38. The analysis numbers in both shape and rock analyses correspond with those of the mechanical analyses.

Iowan till, Peorian loess or both may overlie the gravel. They are generally thin but have been observed to have a thickness of 15 feet. Weathering has removed the carbonates to an average depth of 4 to 6 feet and has oxidized the iron compounds much deeper. Humus has colored the oxidized material of the upper 18 to 24 inches to chocolate-brown (13" "i, Benzo-Brown), this color becoming lighter with increase in depth. The gravel overlies Iowan till in most of the exposures, either oxidized or unoxidized but never leached. However, in a few exposures they have been observed to overlie either Loveland loess, Kansan till, Kansan gumbotil, or Kansan gravel.

Characteristics of the Exposures

One of the most interesting exposures of Iowan gravel is in a pit in the southwest quarter of section 22, Cedar Falls township (T. 89 N., R. 18 W.), Black Hawk county, 2 miles west of Cedar Falls. Here the gravel is exposed along the hillside in an area which has a relief of about 75 feet.

This exposure shows the following section:

	Feet	Inches
6. Loess: leached, oxidized, and filled with humus which colors it to Chocolate-brown (13""i, Benzo-Brown). (Peorian)	2	
5. Pebble band on the surface of the Iowan till. (Iowan)		1
4. Till: oxidized to the usual buff color (19"i, Isabella Color) of the Iowan, leached to a depth of about three feet; several large boulders, the largest having an average diameter of eight feet. (Iowan)	12	
3. Silt and fine sand: unoxidized, leached and well stratified in thin horizontal beds, grading into gravel at the base. (Iowan)	1	
2. Gravel: well stratified, unleached, oxidized to a medium-brown; pebbles show some striations and some stream wear. (Iowan)	10	
1. Till; gray (15""', Mouse-Gray) on the surface when dry, and blue-black when wet; unleached and unoxidized, and contains boulders. (Iowan)	4	

The iron oxide which coats the grains colors the deposit to a rusty-brown (17', Raw Sienna) and cements the gravel so that it will stand in vertical exposure. After the gravel has been exposed in the section for a short time the iron oxide in the outer few inches becomes much harder and cements the gravel more firmly. Leaching has removed the carbonates from the overburden to a depth of 5 1/2 feet, below which both the till and gravel are unleached. Most of the crystalline rocks appear fresh but a few are slightly disintegrated. The material consists chiefly of sand and gravel finer than 3 centimeters in diameter; it is well stratified and interbedded in horizontal beds. The percentage of each size grade is shown in No. 1 of figure 36. The percentage of rounding is shown in No. 1 of figure 37. The rock content of the pebbles between 16 and 32 millimeters in diameter is shown in No. 1 of figure 38.

This exposure represents an irregular mass of Iowan gravel inclosed within Iowan till and is significant from the standpoint of its relationship to the Iowan till. The leaching extends to a depth of about 5 feet in both the till and the gravel, while the oxidation extends to greater depths.

About 1/2 mile south of this exposure there is another exposure of Iowan gravel in a cut along the highway. In this cut the gravel is a small pocket near the surface of the till. It is within leached and oxidized till and likewise is leached and oxidized. The overburden is Peorian loess 2 feet thick.

In the top of an elongated hill near the margin of the Iowan drift area, in the southwest quarter of section 12, Smithfield township (T. 92 N., R. 7 W.), Fayette county, between Fayette and Arlington, 12 feet of Iowan upland gravel is exposed in a group of three pits which are only a few hundred feet apart. In this region there is 120 feet of relief between the pits and the bottom of the valley which is less than 1/2 mile away. About 40 feet of this relief is above the Kansan gumbotil plain. This exposure shows many irregularities. It contains well-stratified beds of gravel in some parts, stratified sand and silt in others, and masses of unstratified or slightly stratified material in still others. Accompanying the variations within the clastic texture of the gravel, there are similar variations in the amount of oxidation and leaching. The coloring by iron oxide varies throughout the exposure from a reddish-brown (11'k, Hazel) in one bed of silt 8 inches thick, through various shades of brown and buff, to gray (21'' 'f, Pale Olive-Buff) unoxidized sand which is highly siliceous and occurs in both beds and irregular masses. The uniform beds of gravel are leached to the usual depth of about 5 1/2 feet, which includes the overburden. However, most of the beds and masses of gray unoxidized siliceous sand and silt contain no calcium carbonate even where they are below this depth and below unleached gravel. There is a wide range in size from large boulders 60 centimeters in diameter distributed through the exposure to beds of fine sand and silt. Most of the gravel is finer than 5 centimeters in diameter, and more than 30 per cent of the material exposed is silt and fine sand which is in irregular masses and interbedded with the gravel. The percentage of each size grade, is shown graphically in No. 2 of figure 36. The percentage of rounding is shown in No. 2 of figure 37. The rock content is shown in No. 2 of figure 38.

The overburden is leached Iowan till and Peorian loess that has a maximum thickness of about 6 feet. Within the upper 16 to 24 inches it is colored to a dark-brown (13" "i, Benzo-Brown), but below this it gradually grades into a lighter shade of brown (17" 'i, Buff-Brown) with the increase in depth.

Another interesting exposure of Iowan upland gravel is in the northeast quarter of section 35, Wayne township (T. 100 N., R. 15 W.), Mitchell county, about 1/2 mile east of McIntire. Here in a pit along the hillside the gravel overlies both Kansan gravel and Loveland loess.

The iron oxide which coats the grains colors the deposit a light-brown (15'i, Ochraceous-Tawny) but cements the mass so slightly that it slumps soon after exposure. The gravel reaches its maximum thickness of 5 feet in the middle of the exposure, from which point it becomes thinner toward the edges, where it has a thickness of about 2 feet. The combined thickness of the gravel and overlying till is 7 feet. The gravel is fairly well stratified in a general horizontal position but is poorly sorted; it shows some cross-bedding, and some steeply dipping beds. Most of the material is smaller than 5 centimeters in diameter, although there are some cobbles as large as 15 centimeters in diameter scattered through the finer material with no relation to the stratification. A few of the pebbles and cobbles show glacially planed surfaces and striations. The percentage of each size grade is shown graphically in No. 3 of figure 36. The percentage of rounding is given in No. 3 of figure 37. The rock analysis is shown in No. 3 of figure 38.

The overburden is Iowan till, colored in the upper 18 to 24 inches to the usual dark brown by oxidation and humus, below which it grades into the usual lighter shades of normal oxidized Iowan till. Only where thickest (5 feet) is there unleached Iowan till above the gravel. Underlying the Iowan gravel is Kansan gravel and Loveland silt. The former shows a marked difference in characteristics from the Iowan gravel and the latter has been partly plowed up and incorporated into the base of the Iowan gravel.

In the northwest part of Mitchell county the Iowan upland gravel is exposed in the northwest quarter of section 14, Otranto township (T. 100 N., R. 18 W.), less than 1/4 mile southwest of Mona. Here on the relatively flat Iowan upland is a pocket of gravel which lies on the Kansan gumbotil and extends through the Iowan drift which at this location is only 5 feet thick. Practically all of the gravel has been removed, but it seems from all available evidence that the gravel was about the same thickness as the Iowan till. Although the exposure is only 5 feet thick there are a few inches of unleached material immediately above the Kansan gumbotil. The complete removal of the gravel and slumping since the pit was last used makes a detailed study of the gravel impossible.

In Howard county in the northwest quarter of the southwest quarter of section 10, Albion township (T. 100 N., R. 11 W.), overlooking the Upper Iowa river, a pit exposes 28 feet of gravel. It is located at the extreme end of a narrow tongue of Iowan drift which extends out into the rugged loess-mantled Kansan drift topography. The top of the exposure is 80 feet above the valley below.

The iron oxide colors the complete section of gravel to a light buffy-brown (17" 'i, Buffy-Brown). It does not cement the gravel but merely helps to compact the mass so that it does not slump readily. In no part of the exposed gravel is there any variation from the usual color. Leaching has removed the carbonates to a depth of 3 to 5 feet, and most of the igneous pebbles appear fresh. The exposure may be roughly divided into an upper 3-foot member and a lower 25-foot member on the basis of size of material and stratification. The upper 3 feet contains some boulders ranging up to 25 centimeters in diameter and a large amount of coarse gravel, all poorly stratified. The lower 25 feet of the exposure consists of well-stratified and cross-bedded gravel ranging between 0.5 centimeters and 2 centimeters in diameter, except for a small amount of sand which is mixed but not interbedded with the gravel. The percentage of each size grade of an average sample of the lower member is shown graphically in No. 4 of figure 36. The percentage of rounding is shown in No. 4 of figure 37. The rock content determined by an analysis of pebbles is shown in No. 4 of figure 38.

The overburden is loesslike silt, colored dark-brown (13" "i, Benzo-

Brown) by oxidation and humus. It is about 1 foot thick; is leached, and grades into the top of the coarse leached gravel which in the upper 10 inches is colored to about the same shade as the overburden.

One-half mile north of Paris in the northeast quarter of section 19, Jackson township (T. 86 N., R. 6 W.), Linn county, 30 feet of Iowan upland gravel is exposed at the top of the hill in a region of rolling Iowan drift topography. This exposure is at the margin of the Iowan drift but at the extreme end of a long narrow recess between two lobes of the Iowan drift.

There is very little oxidation within this gravel, which is light grayish-buff (19''i, Isabella Color) and leached to a depth of 4 to 6 feet, including the overburden, which varies from 2 to 4 feet in thickness. Except for a few disintegrated granites and schists the igneous rocks are unweathered. The gravel is well sorted, and stratified in beds which are essentially horizontal in some parts of the exposure and in other parts dip steeply toward the east. Cross-bedding which is common within the thicker beds, also dips toward the east. At two locations within the pit the gravel is cemented by secondary calcium carbonate, forming a firm conglomerate. A large mass of this conglomerate has a width of more than 40 feet and includes half of the gravel exposed along the west side of the pit. No relationship exists between the type of material and the cementation and stratification. The percentage of each size grade determined by a mechanical analysis is shown in No. 5 of figure 36. The shape is shown in No. 5 of figure 37. Likewise the rock content, determined by an analysis of pebbles between 16 and 32 millimeters in diameter, is shown in No. 5 of figure 38.

The overburden is sandy Iowan till which has been leached of its carbonates and colored by oxidation and humus to a medium dark-brown (13'' ''i, Benzo-Brown) in the upper part but becomes lighter in color with increase in depth.

An exposure of Iowan upland gravel within a region of rolling Iowan drift topography is at the top of an elongated hill in the southeast quarter of section 13, New Oregon township (T. 98 N., R. 11 W.), Howard county. This gravel section is in a region where the pre-Iowan erosion exposed the limestone bedrock in many places. As a result the Iowan glacier found the limestone more readily available and likewise the gravel deposited by it contains a high percentage of limestone.

The gravel in this exposure is overlain by thin Iowan till except along the margin, where it has a maximum thickness of 4 feet. This variation in the thickness of the overburden makes a marked difference in the depth of leaching and the character of the uppermost gravel, as will be shown in the following description. Along the margin where the gravel is overlain by 4 feet of normal Iowan till leaching is to a depth of about 5 feet — 4 feet in the till and 1 foot or less in the gravel. However, in the main part of the pit, where the sandy overburden is only about 1 foot thick, leaching is to a depth of from 2 to 2 1/2 feet. This wide variation in the depth of leaching could be due to either the removal of material by erosion or the contraction of beds by removal of the soluble carbonates. Although possible, there is little basis for the conclusion that the leached material has been removed by erosion. Since the gravel contains about 50 per cent limestone, its removal would reduce the volume of the gravel by one-half. If 4 feet of gravel were leached, the remaining gravel would be only about 2 feet thick. At the upper surface of the gravel of this exposure there is a concentrate of coarser non-calcareous material which is almost entirely unstratified and contains overburden within the interstices. It is a zone which seems to represent a gradation from gravel into overburden. This zone can be easily explained on the basis that the overburden sifted down into the space left as the limestone was dissolved away. In this exposure the zone of concentration is thicker and more distinct where the overburden is thin than where it is thick. Furthermore this relationship is more evident in those deposits containing a high percentage of limestone. Hence, it seems probable that the 16 inches to 2 feet of the leached gravel where the overburden is thin is a concentration from about twice that thickness of original gravel. The thin overburden may have undergone some erosion but not necessarily any great amount. Oxidation colors the mass of gravel uniformly to a light buffy-brown (19"i, Isabella Color) with very little variation in color except in the narrow band of gravel immediately below the overburden, which is colored dark dirty-brown (13" "i, Benzo-Brown) by the addition of humus. In the leached gravel there is no stratification, but below this and towards the base of the section the stratification becomes good. In general the stratified beds are almost horizontal, dipping at a low angle toward the southeast. A large number of small boulders which are almost all platy limestone are scattered through the gravel. These limestones generally lie with their greatest diameters parallel to the stratification. An analysis of the rocks larger than 3 centimeters in diameter shows about 85 per cent to be limestone, of which 45 per cent are angular, 45 per cent sub-angular, and 10 per cent curvilinear in shape. The general characteristics of the gravel are shown in figure 39.

FIG. 39. — Type of gravel of an Iowan upland deposit.

A group of kamelike hills is in section 17, 18, 19, and 20, Center township, (T. 93 N., R. 9 W.), Fayette county, about 2 miles west of Randalia. These knobs which stand out above the surface of the gently rolling Iowan drift are about 5 miles from its margin. Gravel pits expose gravel in the tops of many of these knobs, which are not generally more than 20 feet above the surrounding drift surfaces.

Within these exposures are many irregularities in both gravel and overburden. The overburden is Iowan till which in some places is covered by loess. It ranges in thickness from 2 to 8 feet and shows the usual amount of leaching and oxidation characteristic of these materials. The gravel is in irregularly shaped masses. It is uniform neither in texture, in oxidation, nor in depth of leaching. Practically all of the gravel is smaller than 7 centimeters in diameter, and a large percentage is sand and silt. Some of the material is well stratified in practically horizontal beds, and some of the thicker beds contain cross-bedding. In some places well-stratified sand and silt are as much as 3 feet thick, and in other places they occur as irregular masses enclosed within the gravel. In the latter case many of the beds of sand and silt are folded, crumpled, or otherwise distorted. Oxidation varies from medium-brown (17 i, Raw-Sienna) in the coarser gravel to light-buff (17"b, Cinnamon-Buff) in the sand and silt. There is no definite depth of leaching within the deposits, but under normal conditions where gravel underlies the overburden, leaching is to depths like those of other Iowan gravel deposits. However, the sand and silt are generally non-calcareous wherever exposed. Within the exposures there are inclusions of irregular masses of till only a few feet in diameter. Some appear to be Iowan while others are probably Kansan, although this differentiation is based upon leaching alone. There are also irregular masses of fine silt which are possibly Loveland in age, and near the base of one exposure there are some small masses that look like gumbotil. Clay-balls are common.

The characteristics of these deposits are not out of harmony with their position. They are within a few miles of the margin of the Iowan drift and the stratified sand and gravel is much like that of other similarly located deposits. In an exposure about 6 miles northeast of here both Kansan gumbotil and Loveland loess are exposed below a layer of Iowan till and loess, and in another exposure in the same vicinity Nebraskan gumbotil is exposed. It seems logical to assume that these older materials were transported by the ice and incorporated in the Iowan gravel deposits.

Many other deposits occupying topographic positions similar to these just described are found throughout the northwestern part of this county and the eastern part of Chickasaw county. However, the gravel exposed in them is generally more uniform in every respect. In the other deposits inclusions of Iowan till and older deposits are uncommon and the general character of the gravel is more like that of the Iowan upland gravel previously described.

From studies of the Pleistocene deposits in northwestern Iowa, Carman recognized and described Iowan drift and Iowan gravel. The detail in which this work was done and the long period of time devoted to the study enabled him to observe many exposures, some of which are now covered by slumped material. He described one very significant exposure of interbedded Iowan till and gravel as follows: [50]

"By far the greatest example of interbedding of gravel and till observed was found in the east bluff of Mill creek in the west half of section 14, Cherokee township, three miles north of Cherokee. Mill creek at this place flows against the base of the east slope of its valley, and this slope rises very steeply 100 to 120 feet to the crest of a narrow ridge which overlooks the valley of Mill creek on the west and the Little Sioux valley on the east. The good exposures just south and north of the line through the center of section 14, were distributed through a distance of about 80 rods, and were found in little gullies and slides that gave exposures of the underlying material. The lower 30 to 40 feet of the valley slope is gentle but showed a few exposures of typical Kansan till. Above this is a steep slope of 75 to 100 feet, consisting of about equal parts of interbedded Iowan till and gravel which alternate several times in the vertical section. The gravel horizons range in thickness from mere seams to 20 feet, but a common thickness is 10 to 15 feet.

"Most of the gravel is fresh and has a light color owing to the predominance of gray limestone pebbles. It contains many clay-ball pebbles from the associated Iowan till and some of Kansan and Nebraskan tills. The interbedding of gravel and till and the presence of the clay-balls of the associated till in the gravel show that the gravel belongs to the same stage as the till.

"These exposures in the Mill creek bluff of section 14, were such good ones that the following sections are given, recording in detail the succession found in several of the better exposures. The exposures were all mere gully washes and were partly obscured by slumping and surface accumulation. The sections are given in order from south to north.

Section A. — The most southern exposure, that covered approximately all of the height of the slope, was 30 to 40 rods south of the quarter-section line. This exposure is shown diagrammatically in A of figure 40.

	Feet
11. Grass-covered, gravelly, clay slope rising to the top of the ridge, which is here 106 feet above the creek. Probably Iowan till, but it may contain some gravel layers	12
10. Till, light brownish gray, with pebbles and cobbles. Iowan The exposure is not entirely continuous and the division may contain some gravel. Numbers 11 and 10 combined would make a till zone 30 feet thick, which is greater than for any single zone of till known along this bluff. There is also the unexposed zone (9) below, which may be largely till. It is not probable that numbers 11, 10 and 9 form a single continuous till zone, or even that numbers 10 and 11 are without a single gravel layer.	18
9. Unexposed slope	10
8. Gravel, light-colored	4

50 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 84-88, 1931.

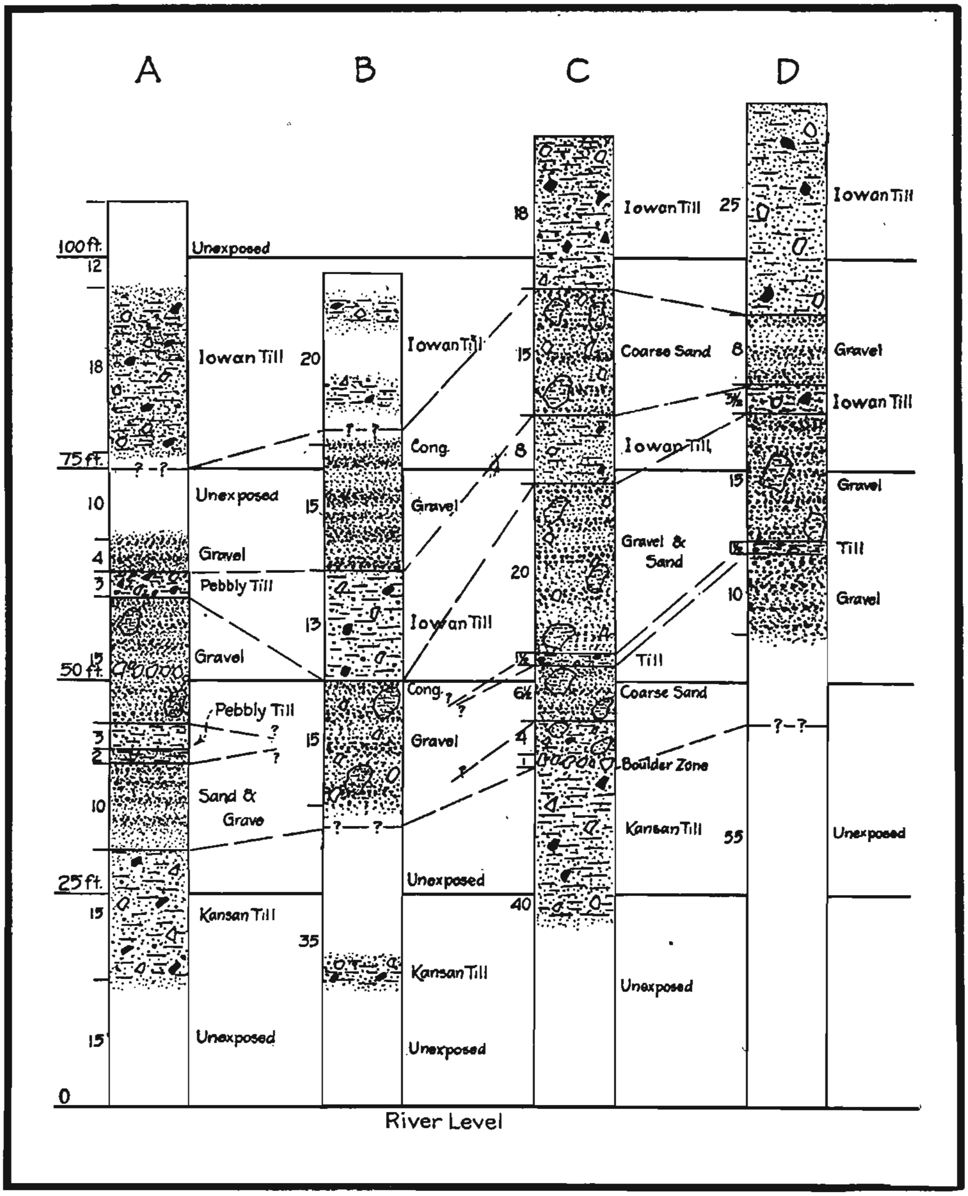


FIG. 40. — Columnar sections of exposures in the east bluff of Mill creek in the west half of section 14, Cherokee township. The probable correlation of the numbers of the several sections is indicated (Section by Carman).

7. Till, light brownish gray, with pebbles, cobbles and small ocherous masses. In some places the pebbles and cobbles make up fully half of the whole. The basal contact on the gravel is very sharp, without any alteration or deformation of the gravel	3
6. Gravel with large pebbles and boulders scattered through it and a layer of boulders about 5 feet above the base. Many included clay-balls and masses of Iowan till are present. The gravel has a light color and limestone is the dominant material. Shale pebbles are quite abundant. This is the typical gravel associated with the fresh Iowan till	15
5. Till, brownish yellow, which breaks into elongated chunks	3
4. Till, brownish blue-gray, sandy	2
3. Sand and gravel; at top a fine-grained yellow sand; only partly exposed	10
2. Slope with several exposures of oxidized brownish yellow Kansan till	15
1. Unexposed slope to creek level	15

Numbers 1 and 2 of this section are Kansan till. Above these the Iowan section gives at least three gravel zones, and a better exposed section probably would increase the number.

Section B. — The gully just north of the quarter-section line fence exposed the following, beginning 98 feet above the creek and passing downward. The columnar section is shown in B. of figure 12. (figure 40 of this report.)

	Feet
5. A pebbly clay slope with a few exposures of brownish gray till	20
4. Gravel horizon; cemented to a conglomerate near the top	15
3. Till, brownish yellow-gray; harder and more compact than number 5. Where it is fresh it breaks into irregular chunks and crumbles to a sandy clay. The lower 3 feet includes much gravel	13
2. Gravel, light colored, with pebbles, cobbles, clay-balls, and some larger masses	15
In the gully the upper 2 feet of this horizon is cemented, forming a calcareous conglomerate, but this does not continue horizontally beyond the gully. The lower part of the slope is so badly slumped that the lower contact of the gravel could not be exposed.	
1. Unexposed to creek level, except for one small outcrop of oxidized, brown Kansan till at 15 feet above the creek	35

This section shows two distinct layers of fresh gravel, each at least 15 feet thick, and each overlain by Iowan till. A cemented horizon is found at the top of each gravel zone. The cementing material is calcareous and the cementation is sufficient to make firm conglomerate, large blocks of which lie on the slope below the outcrop. The cemented parts differ in thickness and seem to be irregular cemented masses rather than continuous beds. This cementation is due to the evaporation which takes place when ground water percolating downward passes from the compact till to the porous gravel. If the water has become saturated with calcareous material this evaporation will cause deposition.

Section C. — This exposure was in a gully about 40 rods north of the quarter-section line fence. It is shown in C of figure 12. (figure 40 of this report.)

	Feet
9. Gravelly clay slope	18
8. Sand, ferruginous, coarse, with pebbles, cobbles and clay masses	15

7.	Till, sandy, brownish gray, breaks out in irregular chunks and pulverizes to a sandy clay	8
6.	Gravel, ferruginous, or coarse sand with pebbles, cobbles and numerous large clay masses, some of which are 2 to 4 feet across	20
5.	Till, bluish gray, with brown streaking along joints	1½
4.	Sand, coarse, with pebbles, a few cobbles and clay-balls. The lower 18 inches is about half clay in the form of clay-balls	6½
3.	Till, yellowish brown, with many pebbles and pockets and seams of sand	4
2.	Gravel, coarse, with cobbles and boulders	1
1.	Brown Kansan till was exposed for 18 inches below the top of the zone and at one point 10 feet lower. Remainder of division to creek level, unexposed	40

Section D. — At the place where the bluff begins to bend to the west there is a gully which branches about 50 feet above the creek. The following exposure was seen in the north branch of this gully. It is represented in D of figure 12. (figure 40 of this report.)

		Feet
7.	Pebbly clay slope rising to the crest at 118 feet above the creek	25
6.	Gravel with clay-balls	8
5.	Till, brownish gray	3½
4.	Gravel with cobbles and clay masses	15
3.	Till, brownish yellow, plastic, sandy	1½
2.	Gravel with clay masses	10
1.	Unexposed to water level	55

"Several other exposures to the north show a part of the section and in every case where more than a few feet is exposed an alternation of gravel and till is to be seen.

"The beds of all these gullies are filled with boulders. Pink and gray granite of the fine-grained type predominate, but basalts are numerous and limestones are more prominent than is common among boulders.

"The sections given above show two, three and four gravel horizons, and few of the exposures were continuous enough to demonstrate that other thin gravel layers are not present. Some similarities of sections which are very close together were noted but on the whole it appears that the individual horizons are not continuous through the length of the bluff. Figure 12 shows such correlations as can be made between the various members of the several sections.

"The fresher till interbedded with gravel in the upper parts of the exposures just described is interpreted as Iowan. The till exposed in the lower 30 to 40 feet of the bluff is darker and firmer than that which is associated with the gravel beds and is interpreted as Kansan. In the lower ends of several of the gullies toward the north end of this bluff the Nebraskan drift is exposed.

"At several places in the exposures described above the interbedded gravel contains such a great number of clay-balls that they constitute a very important part of the whole. These clay-balls indicate that the material had not been carried far before deposition, for clay material could not have withstood the wear incident to long transportation, even though it was firmly frozen. As the clay-balls were formed probably on or near the edge of the ice sheet, their presence indicates the nearness of the ice front at the time of gravel deposition."

An exposure of upland Iowan gravel, near the southern extension of the Iowan drift of northwestern Iowa, is in the northeast quarter of the southwest quarter of section 10, Boyer Valley township (T. 88 N., R. 37 W.), Sac county. This is in a region of gently rolling Iowan drift topography. The gravel is exposed in four separate gravel pits which are only a few yards apart and cover much of the highest part of a hill. These deposits represent irregular masses of gravel within the Iowan till and do not extend above the general level of the Iowan drift. The overburden is loess ranging in thickness from 1 to 4 feet. It is leached of its carbonates and colored by oxidation to the usual buff color (17'' ', Wood-Brown) below the soil zone which is colored brown (13'' ''i, Benzo-Brown) by oxidation and the addition of humus. The lower 6 inches of the loess contains some sand and pebbles from the surface of the underlying gravel. In the bottoms of the exposures the gravel overlies typical Iowan till, unleached and colored buff (17'' 'd, Vinaceous-Buff) by oxidation in the upper 6 inches, below which it is gray (15'' '' ', Mouse-Gray). In some places this till is immediately overlain by fine sand.

Oxidation has colored most of the gravel of the section to a rusty-brown (17i, Raw-Sienna), but within a few of the beds the color is either a slightly lighter or darker shade. The depth of leaching in the gravel varies inversely with the thickness of the overlying loess; the combined depth within the two is about 3 1/2 feet. Weathering has disintegrated some of the coarse crystalline rocks along their margins. The gravel is well stratified in thin, nearly horizontal beds. Rarely and only within a few of the thickest beds is there any cross-bedding. The sand at the base of the gravel is in thin beds like that of the gravel. A few boulders, the largest having an average diameter of about 35 centimeters, are scattered through the gravel. There are also clay-balls; some are as large as 10 centimeters in diameter but most are smaller than 1 centimeter. A mechanical analysis of the average gravel is shown in No. 6 of figure 36. Within this average material 58 per cent is soluble in hydrochloric acid. The percentage of rounding is shown in No. 6 of figure 37. The lithology, determined by an analysis of pebbles is shown in No. 6 of figure 38.

In the southwest part of Cherokee county, in the northwest quarter of section 35, Diamond township (T. 90 N., R. 20 W.), there is a group of three kamelike knobs on the Iowan upland. Gravel has been removed from each of the knobs; in two of them the gravel face is concealed by slumping, while in the other it is well exposed. The overburden has an average thickness of 3 feet. It is leached of its carbonates and colored light-brown (17'' 'i, Buffy-Brown) by iron oxide and humus. It consists of sandy silt with pebbles numerous at the base but less numerous toward the top.

The characteristics and structure of the gravel vary widely throughout the exposure. The oxidation colors most of the material to various shades of rusty-brown (17''i, Tawny-Olive), and in some places it cements the gravel into a compact mass which crumbles under slight pressure. The remaining sand is unoxidized and light-gray in color. Leaching has removed the carbonates from the 3 feet of overburden and to a depth of about 1 foot from the underlying gravel. Below this there is a small amount of limestone in all of the gravel, but some of the sand is non-calcareous. Some of the gravel is cemented by secondary lime. The entire mass of gravel has a very irregular structure; only the lowest bed, which is cross-bedded sand and containing some pebbles, is continuous throughout the exposure. The other material, both gravel and sand, is very irregular in thickness and thins out within short distances. Some of the gravel is stratified, but most of it is in poorly sorted, unstratified beds. The sand is well stratified and contains much cross-bedding, which dips at an angle of about 35 degrees in every direction, although generally either north or south. The material of this section ranges from sand to boulders which are about 25 centimeters in diameter. Pebbles are scattered through the finer beds of sand. The per cent of rounding is high for gravel of this type, as is especially noticeable in the coarser material. Even the dark pink quartzites, which here occur in unusually large numbers, show considerable wear. Almost all of the many clay-balls are smaller than 3 centimeters in diameter, but some are as large as 10 centimeters.

Upland Iowan gravel is especially well exposed in kamelike hills in the south central part of O'Brien county. One of the best exposures is in the northwest quarter of section 22, Liberty township (T. 93 N., R. 41 W.), within an area of rolling Iowan drift topography. Here the gravel exposed in a gravel pit near the top of the hill represents a mass partly enclosed within Iowan till. This exposure has been described in extreme detail by Carman,[51] in his report on the Pleistocene Geology of northwestern Iowa.

Another exposure of Iowan upland gravel is in the southeast quarter of the northwest quarter of section 24, Lincoln township (T. 97 N., R. 40 W.), O'Brien county. The gravel is exposed at this location in two pits only a few yards apart near the upland in a region of gently rolling Iowan drift topography in which there is not to exceed 50 feet of relief. This deposit does not occur in a kame but is below the gently sloping Iowan drift surface. The gravel is overlain by 2 to 3 feet of leached loess, which is colored chocolate-brown (17'' ', Wood-Brown) by oxidation and humus. This overburden has an irregular contact with the underlying gravel and in places appears to grade into it.

The small amount of oxidation colors the gravel light-buff (17'' 'b, Avellaneous) throughout most of the exposure, but the color varies slightly with different textures. The 11-foot section of gravel is unleached and almost all of the lime present is in the form of limestone pebbles. There is a distinct difference in the structure and clastic texture of the two pits. In the north pit there is a wide size range from clay to beds of coarse gravel which contains cobbles and occasionally a large boulder. About 20 of these boulders lie in the bottom of the pit. However, the average gravel of this exposure is similar to that of the other pit. The structure is very irregular and much of the material is stratified in beds of variable thickness which dip at a low angle toward the southeast. There are many lenses and some cross-bedding, both dipping primarily in the same direction as the stratification. In the south pit the structure and texture are uniform throughout the exposure. All of the gravel is finer than 3 centimeters in diameter and the average is like that of the mechanical analysis shown in No. 7 of figure 36. The gravel is uniformly stratified in beds which dip toward the southwest at an angle of about 45 degrees. Clay-balls are common in both of these pits. Dark-pink quartzite boulders, as described in the exposure in the southeast part of Cherokee county, are rare. A rock analysis of the pebbles is shown in No. 7 of figure 37. The shape of the different size grades is shown in No. 7 of figure 38.

As shown in figure 34, there are many exposures of Iowan upland gravel within the Iowan drift areas of Iowa. However, all of these

[51] Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 93-95, 1931.

are similar in most aspects to the few representatives which have been described.

Relations of the Gravel

The upland Iowan gravel deposits show their relations to associated materials in many exposures, some of which have been previously described.

In the southwest quarter of section 22, Cedar Falls township (T. 89 N., R. 14 W.), Black Hawk county, an irregular pocket of gravel overlies unleached and unoxidized Iowan till. It is enclosed along the sides by Iowan till which is unleached and is in part oxidized, and in part unoxidized. It is covered by 15 feet of Iowan till and loess which is oxidized and leached in the upper part. The gravel is oxidized but unleached except in a bed of sand at the top. As previously stated, the non-calcareous character of this sand need not represent leaching, for similar non-calcareous sands have been seen entirely enclosed within calcareous gravel. Therefore, there is no reason to believe from the character of the gravel that this is not a pocket of Iowan gravel buried deeply within the Iowan till, as all other evidence indicates.

Carman has described Iowan gravel interbedded with Iowan till in the west half of section 14, Cherokee township (T. 92 N., R. 40 W.), Cherokee county. In his descriptions of the gravel he indicates the unquestionable relationship to the Iowan till within which it occurs. He states:

"The sections given above show two, three and four gravel horizons, and a few of the exposures were continuous enough to demonstrate that other thin gravel layers are not present. Some similarities of sections which are very close together were noted but on the whole it appears that the individual horizons are not continuous through the length of the bluff.

"The fresher till interbedded with gravel in the upper parts of the exposures just described is interpreted as Iowan. The till exposed in the lower 30 to 40 feet of the bluff is darker and firmer than that associated with the gravel beds and is interpreted as Kansan."

In the exposure described near Mona, Iowa, in the northwest quarter of section 14, Otranto township (T. 100 N., R. 18 W.), Mitchell county, the calcareous gravel lies directly upon Kansan gumbotil and extends through the entire thickness of the thin Iowan till. Oxidized and leached Iowan till is exposed along the sides of the pit in several places.

Another exposure of this gravel which is closely related to the underlying Kansan deposits is about 9 miles southeast of Mona, near Stacyville, in the central part of section 18, Stacyville township (T. 100 N., R. 16 W.), Mitchell county. Here, in a shallow road cut, about 2 1/2 feet of Iowan gravel is exposed overlying Kansan gumbotil. The gumbotil is closely related to a large exposure of Kansan gravel less than 100 yards to the east. This Iowan gravel is closely related to the thin Iowan till which overlies the Kansan drift within this area.

Still another exposure in Mitchell county in which the relationship of the Iowan gravel to older deposits is shown is in the northeast quarter of section 35, Wayne township (T. 100 N., R. 15 W.), about 1/2 mile east of McIntire. Here unleached Iowan gravel overlies leached Kansan gravel. In the south part of the pit the Iowan and Kansan gravels are separated by a 6-inch bed of gray, leached Loveland silt which along its northern margin is broken up and incorporated in the base of the overlying Iowan gravel. The Iowan gravel here is overlain by Iowan till which, where it is thin at the center of the exposure, is leached, but which, where it thickens toward the margins of the exposure, is in some places unleached.

Kansan gumbotil has been plowed up and incorporated in large masses in the base of the Iowan gravel in an exposure in the northeast quarter of the northwest quarter of section 27, Perry township (T. 89 N., R. 10 W.), Buchanan county. This is within the Iowan drift area, and a thin layer of Iowan till and Peorian loess overlies the gravel.

Oxidized and unleached till is exposed at the base of many of the Iowan gravel exposures distributed throughout the Iowan areas of both northeastern and northwestern Iowa. In many places it is not possible to state definitely whether the till is of Iowan or Kansan age, because where the leached zone of the Kansan has been removed by erosion before the deposition of the thin Iowan till which now is also oxidized, these two tills might both be exposed and not differentiated. This is especially true in northwestern Iowa, where the gumbotil and leached Kansan till have been eroded away. However, in most exposures a comparison of the till underlying the gravel with that of the till exposed along the sides of the gravel affords strong evidence as to whether the tills are of the same age. Almost every exposure of gravel studied shows till either at its base, along its sides, or in both positions.

The overburden is Iowan till, Peorian loess, or sandy silt. Iowan till which is sometimes from 2 to 4 feet thick is the overburden in many exposures and many of these are also overlain by Peorian loess. However, in a few exposures the gravel is overlain by sandy silt; the deposition of which probably continued during loess deposition and thus the gravel was not covered by loess. In some exposures loess is the only material overlying the gravel. Weathering processes have oxidized these overburdens and leached them of their carbonates to a depth of about 5 feet.

The relations of the gravel deposits to the including till sheet and to the general topography are important in the interpretation of their origin. Four types have been recognized and described. Of these the most common type is small kamelike hills on the surface of the drift plain. Some of these hills are almost entirely gravel, covered by a thin veneer of till, loess, or possibly both; and others are essentially till in which one or more pockets of gravel occur. There is a wide range in the sizes of these gravel deposits, some being small and shallow and others large and extending deep down into the till, perhaps in some cases to its base. Almost as common as the small hills above are irregular pockets of gravel which are entirely enclosed within Iowan till and loess. Their upper surfaces are at practically the same level as the general drift surface and they are seldom covered by more than 6 feet of overburden. In a few places the gravel is in irregular masses deeply buried within Iowan till. Carman has described deposits in northwestern Iowa as interbedded with Iowan till, apparently as large lenses. Although these are well exposed where described, they have not been observed elsewhere. The rarity of the last two types of gravel deposits is not at all strange, because each represents an unusual type that could not be included within the normal thin Iowan till.

The Age of the Gravel

The position of the gravel deposits in relation to the Iowan drift surface and the amount of alteration which they have undergone show that they were deposited in their present positions during the melting of the Iowan ice. All of the deposits are closely associated with the Iowan till; some occur as masses within the till and others as outwash on its surface. Some of the masses now included within the till were frozen masses of gravel picked up by the glacier from the surface over which it passed and redeposited within the till. These masses had been formerly deposited either in front of the advancing Iowan ice or during pre-Iowan time.

THE IOWAN TERRACE GRAVEL

The Distribution of the Gravel:

The Iowan ice advanced over the eroded surface of the Kansan drift and deposited a thin layer of till which was spread over this surface like a blanket. These older valleys were not filled by this Iowan till but served as drainage courses for the streams flowing from the melting ice that carried sand and gravel which was deposited along these valleys within and beyond the Iowan drift area. However, in northwestern Iowa, some of the valleys that were eroded in the Kansan drift did not extend into the area covered by the Wisconsin glacier and thus did not receive drainage from either the Iowan or Mankato ice sheets. However, these valleys contain extensive gravel terraces, the gravel having been derived from the eroded material of the drift during the Loveland interval. Valleys of the same origin and age extended into the Iowan drift area carrying drainage from the melting ice and receiving the glaciofluvial outwash carried by the streams. It is evident that in northwestern Iowa at least some Loveland gravel was in the valleys before the advance of the Iowan glacier and constitutes part of the gravel fillings. The Loveland and Iowan terraces are so similar that they cannot be differentiated except on the basis of relations to surrounding materials and location in relation to source material. It is probable that the valleys whose heads lie within the Iowan drift area contain gravel of both Iowan and Loveland ages which cannot be differentiated, and in these valleys there is no doubt but that they contain Iowan gravel beyond the Iowan drift margin. Since it is certain that the Iowan gravel forms most of the terrace material within the Iowan area and since the presence of Loveland gravel has not been proven, these terraces will be mapped as Iowan. However, beyond the Iowan drift margin, all of the evidence is in favor of the Loveland gravel forming part of the deposit, even though it may be partly reworked by the streams which deposited gravel as they flowed from the Iowan glacier. These will be mapped as unidentified, except where the relations are such that their age can be definitely determined. Even though no Loveland gravel has been found in northeastern Iowa, the same system of mapping will be used.

Streams flowing from the melting Mankato glacier sometimes cross the Iowan drift area, involving a problem of differentiation similar to that of the Iowan and the Loveland, and where they continue beyond the Iowan margin, it makes gravel of three ages possible. These also, unless definitely differentiated, are included as undifferentiated gravel.

The distribution of the exposures of terrace gravel in the valleys within the Iowan area which did not receive Mankato glacial drainage is shown in figure 41. However, this does not mean that all of the Iowan outwash gravel was deposited as terraces within the Iowan area since a large percentage of the undifferentiated gravel was deposited by streams flowing from the melting Iowan ice.

The exposures of Iowan terrace gravel represented in figure 41 are almost all gravel pits from which the gravel has been removed for road surfacing. However, some are artificial constructional cuts, natural cuts along streams, or prospects by the Iowa State Highway Commission. These gravel terraces are almost continuous along the valleys. The number of exposures mapped is no criterion of the abundance of the gravel but rather an indication that the clastic character as well as the topographic and geographic location is such that they have been naturally exposed or that there has been a greater demand for them at these locations for commercial purposes.

The Characteristics of the Gravel

General Characteristics:

The Iowan terrace gravel is present in the valleys of the Iowan drift region. Most of the present streams have intrenched themselves in these broad gravel fillings, and the remaining parts have formed terraces which differ greatly in height, some being as much as 100 feet above the streams.

In some exposures the gravel was observed to overlie oxidized till which could be either Iowan or older. It is impossible to determine the age of the till in most places, for none of the exposures show a contact of the till along their sides with the till underlying the gravel. In none of the exposures was the gravel underlain by gumbotil or any other good horizon marker. The overburden is of two types: coarse, unstratified, sandy silt, which contains pebbles in decreasing amounts with increase in height above the gravel, and typical Peorian loess which is usually entirely free from pebbles. In some places the

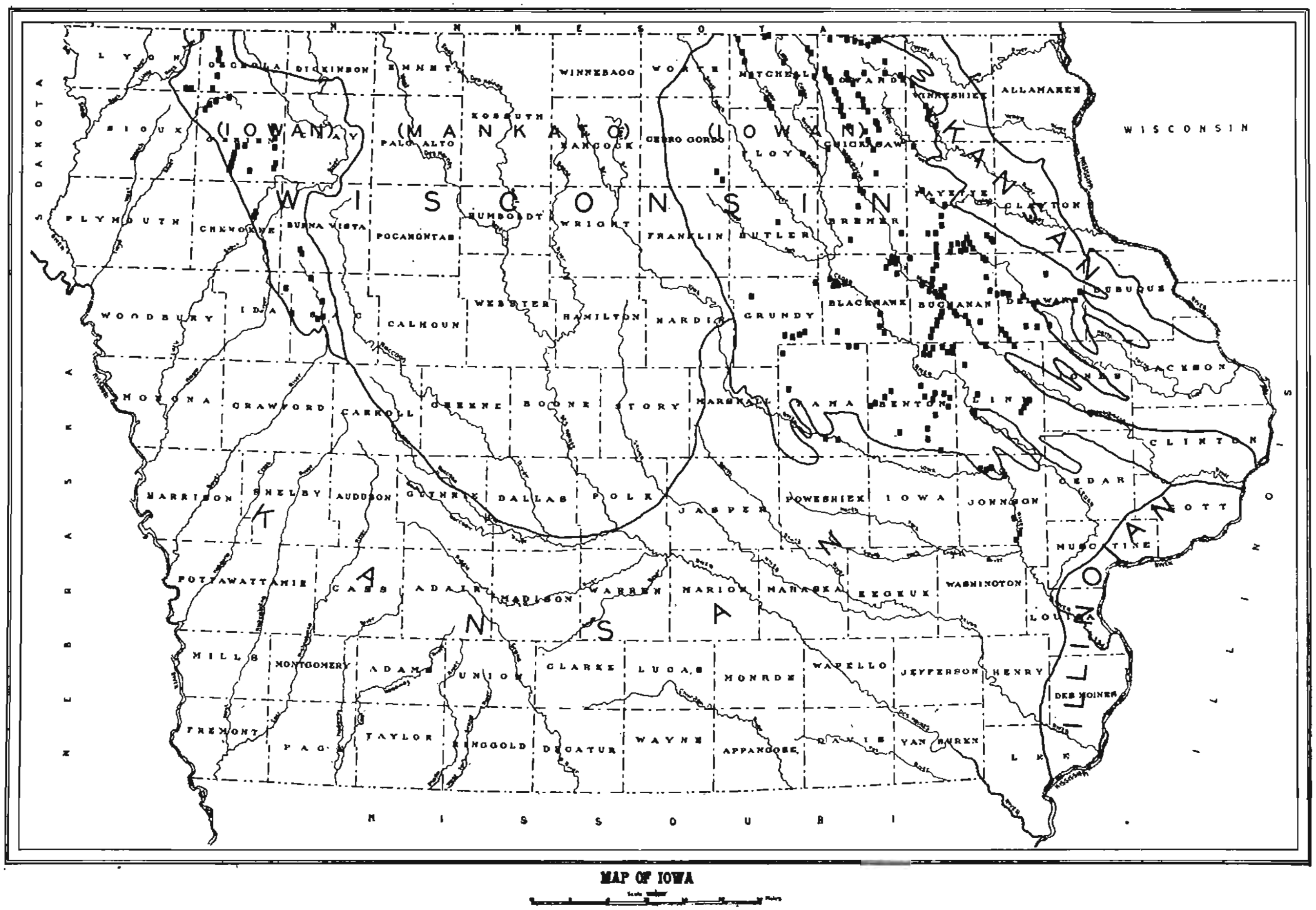


FIG. 41. — The squares show the locations of Iowan terrace gravel exposures within the Iowan drift area of Iowa.

sandy silt grades upward into the loess. In no exposure was there any suggestion of a time interval between the deposition of the gravel and overburden.

Since deposition, weathering has developed some changes within the gravel and overburden but they are not as uniform as those changes within the Iowan upland gravel. The depth at which the carbonates occur within the overburden and gravel varies from a few inches to as much as 20 feet. This variation is not due primarily to differences in the depth of leaching but to lithology, topographic position, and subsequent erosion. In an exposure containing average lithology and texture, unaffected by subsequent erosion or deposition, leaching has been effective to about the same depths as in normal sections of Iowan upland deposits, from 4 to 6 feet. If there is any marked difference, leaching is to slightly greater depths within the valley deposits, which is probably due to the greater freedom of the ground water circulation. Most of the finer material appears fresh and only rarely is there any disintegration within the cobbles and boulders. The coloration varies from gray, unoxidized gravel (17"b, Cinnamon-Buff) in certain exposures in northwestern Iowa to dark-buff (17"i, Tawny-Olive) in some exposures in northeastern Iowa. The more common color is medium-buff (17" 'b, Avellaneous to 19"i, Isabella Color). In a few exposures, certain beds are colored dark-brown (11'm, Chestnut-Brown) by oxidation of the iron or black by manganese dioxide. There is no cementation by either iron oxide or calcium carbonate in any of the exposures.

In northeastern Iowa most of the exposures within the Iowan drift area may be roughly divided into three members. In descending order they are: overburden, coarse and average gravel, and sand and fine gravel. The thickness of each of these members varies widely throughout the different exposures. In northwestern Iowa the exposures show only two divisions, overburden and average gravel. The fine gravel and sand of the lower member of northeastern Iowa is either missing or unexposed.

The overburden has an average thickness of about 3 feet but ranges from a few inches to more than 6 feet. In no place is there any indication of a time interval between it and the underlying gravel with which it is interbedded in certain exposures. Where the overburden is loess it is colored by oxidation to the usual color of loess — chocolate-brown (13" "i, Benzo-Brown) in the upper 2 to 3 feet by oxidation and humus and deeper down by oxidation alone to medium-buff (19"i, Isabella Color). It is unstratified and only rarely contains pebbles except in the lower few inches. The sandy silt which commonly overlies the gravel is colored to light chocolate-brown (17"', Wood-

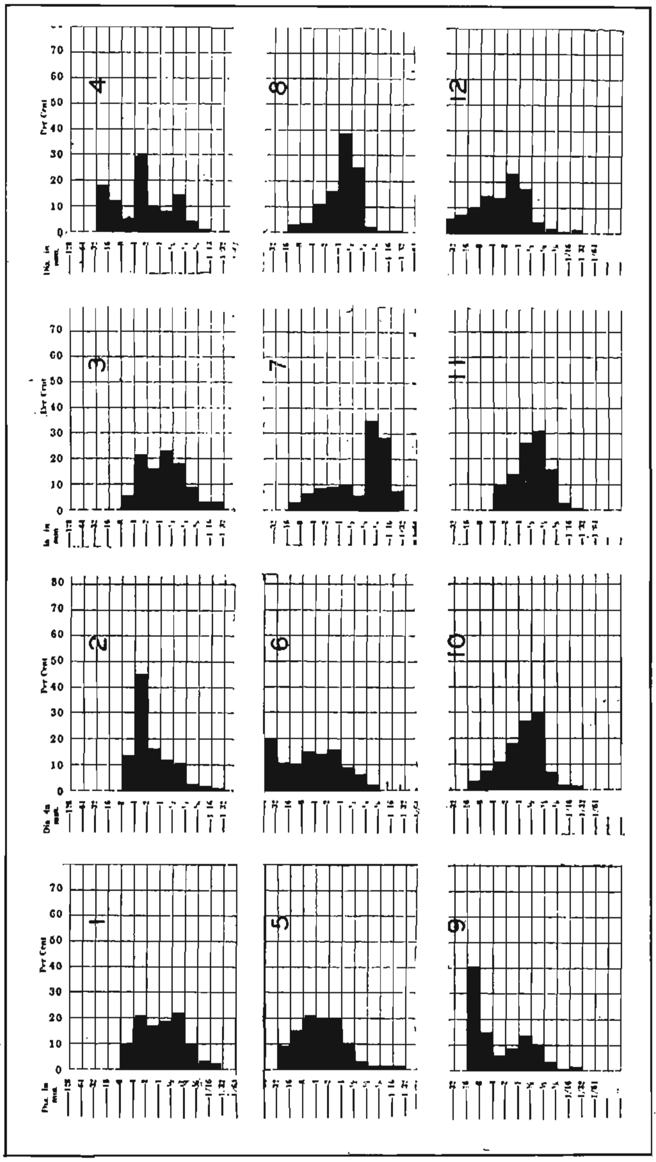


FIG. 42.—Graphs showing mechanical analyses of Iowan terrace gravel. The numbers of this figure correspond with those of figures 43 and 44.

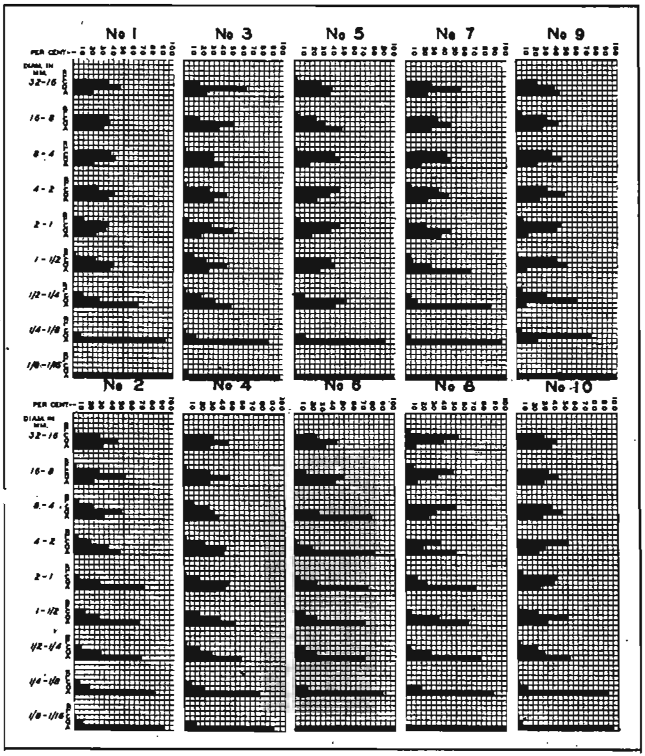


FIG. 43. — Graphs showing shape analyses of each size grade between 1/16 and 32 millimeters in diameter, of the Iowan terrace gravel. The numbers of these analyses correspond to those of figures 42 and 44. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

Brown) in its upper part but is slightly lighter toward the base, where it exceeds 2 to 3 feet in thickness. Within it stratification is rare, but pebbles occur in the basal portion and are sometimes scattered sparsely throughout its entire thickness.

The second member, which is coarse and average material, is not present in all places, but where it is absent the overburden lies in contact with the finer material which has practically no commercial value and thus is seldom exposed. Where the coarse and average material is present it may be only a few feet thick or extend to the base of the exposure as found in many places in northwestern Iowa. Although there is a wide textural range from fine sand to boulders, most of the gravel is sandy, as is shown in the mechanical analyses of figure 42. The material shows little wear as is shown in figure 43, but more wear than within the Iowan upland deposits. The general lithology shown in figure 44 is similar to that of the Iowan upland deposits except for the absence of clay-balls and the occurrence in some deposits of a higher percentage of siliceous material and of the harder, more resistant igneous rocks. As previously stated, the color varies from gray unoxidized gravel to that which is colored by iron oxide to a dark-brown. Thin beds are colored black by manganese dioxide. Except in the upper layer of coarse heterogeneous material at the base of the overburden the gravel is well sorted and stratified in approximately horizontal beds within which cross-bedding, and lens-and-pocket structures are common.

The lower member consisting of fine gravel and sand is seldom well exposed because of its low commercial value. It varies in thickness as do the other members and in some places constitutes practically all of the section. It consists of various-size grades of sand and fine gravel within which may be included an occasional cobble or boulder. It consists essentially of siliceous and hard crystalline rocks. Carbonates either as limestone pebbles or secondary deposition may or may not be present. It shows various degrees of oxidation of the iron compounds which do not cement the gravel but merely color it to various shades from gray (21"f, Pale Olive-Buff) to dark-buff (17"i, Tawny-Olive). Stratification and cross-bedding are good, although interrupted in places by lenses and pockets of gravel and sparsely scattered boulders and cobbles.

Characteristics of the Exposures

The characteristics of the Iowan terrace gravel vary so widely that no one description would be adequate for an entire area. Regardless of the differences there are certain features which they have in common that can be used in discussing their characteristics. The gravel exposures can be divided into the following groups: (1) those which are highly siliceous and contain little if any carbonates, (2) those which contain a high percentage of carbonates, and (3) those in which the percentage of carbonates is intermediate between types one and two. In describing the Iowan terrace gravel the exposures will be grouped under these divisions, although there is a complete gradation from the non-calcareous to those consisting almost entirely of carbonates. The greatest percentage of the exposures are of the intermediate group.

Non-calcareous gravel:— Although observed along several valleys

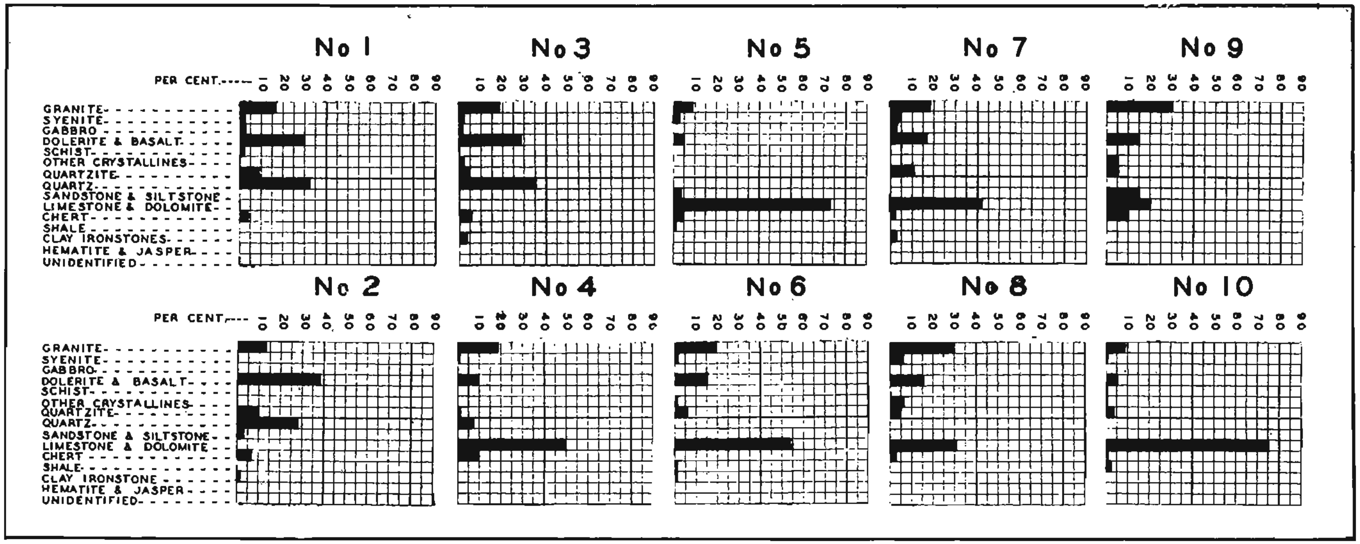


Fig. 44. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond with those of figures 42 and 43.

in northeastern Iowa this group of exposures represents only a small percentage of the exposures of Iowan valley gravel.

One of the best exposures of this type of gravel is located in the northwest quarter of section 2, Jenkins township (T. 99 N., R. 15 W.), Mitchell county. Here along a tributary to the Wapsipinicon river, 1/2 mile south of McIntire, the gravel is exposed in a terrace which is about 30 feet above the level of the stream and only a few feet below the flat Iowan upland. The gravel is exposed to a depth of 15 feet in a fresh unslumped road cut.

The oxidation colors the different beds of highly siliceous gravel to shades varying from light-buff (19"i, Isabella Color) to reddish-buff (17"i, Tawny-Olive), but in no place is it sufficient to cement any of the material. No carbonates, either primary or secondary, are exposed in the entire section. All of the gravel appears fresh. The upper 5 feet of the gravel is almost entirely sand, deposited in thin, horizontal beds within which cross-bedding is not common. About the only irregularities are pebbles smaller than 2 centimeters in diameter scattered sparsely throughout this finer material. The lower 8 feet differs from the upper 5 feet in that there are more pebbles scattered through the finer material and thin beds, small lenses, and pockets of coarser material are included within the stratification. Nothing within the exposure exceeds 3 centimeters in diameter and less than 4 per cent is larger than 8 millimeters in diameter. The percentage of each size grade of a sample of average material is shown in No. 1 of figure 42. The percentage of rounding of each size grade between 1/16 and 32 millimeters in diameter is shown in No. 1 of figure 43. The rock analysis given in No. 1 of figure 44 shows that the pebbles between 16 and 32 millimeters in diameter are chiefly siliceous. The overburden is sandy loess-like silt ranging from 1 to 2 feet in thickness. It is colored dark-brown (13" "i, Benzo-Brown) by humus and oxidation. Scattered through it are a few pebbles which increase in number toward the base. No contact with material underlying the gravel was exposed.

Another exposure similar to the one just described is in the southwest quarter of section 27, Wayne township, about 1 1/2 miles to the northwest. This exposure also occurs in a terrace which is about 30 feet above the level of the stream and at about the same level as the surrounding Iowan upland drift surface. The material and structure are very much like that of the exposure just described except that a few limestone pebbles were found within the non-calcareous gravel in one part of the exposure at a depth of 6 feet.

In the southwest quarter of section 3, Sumner township (T. 88 N., R. 9 W.), Buchanan county, is an exposure of Iowan terrace gravel a few hundred feet east of the bridge on primary 11 over the Wapsipinicon river, south of Independence. Here in a terrace which stands 25 feet above the river a gravel pit has exposed 15 feet of material, 6 feet of overburden, and 9 feet of gravel.

The gravel exposed in this section resembles a recent deposit. It is gray and shows no oxidation of iron compounds. Although there is no evidence of leaching, the gravel contains no carbonates, either primary or secondary. None of the rocks show signs of weathering or disintegration. Within the 9 feet of gravel exposed, nothing exceeds 3 centimeters in diameter, and less than 1 percent is larger than 8 millimeters in diameter. However, by digging 2 feet deeper in the bottom of the pit, a bed of pebbles was encountered which had a maximum average diameter of 4 centimeters. The percentage of each size grade, determined by a mechanical analysis, is shown in No. 2 of figure 42. All of the coarser material has been slightly rounded by stream action, but the finer grades still retain most of their angularity, as is shown in No. 2 of figure 43. The rock content determined by a pebble count is shown in No. 2 of figure 44. Although the gravel is well sorted, it displays a very complex structure consisting almost entirely of cross-bedding, lenses, and pockets as shown in figure 45.

FIG. 45. — Stratification within an exposure of Iowan terrace gravel.

The overburden is 6 feet thick. The upper 4 feet consists of light-chocolate (17" 'i, Buff-Brown) colored silt, containing small pebbles, and it becomes slightly coarser with increasing depth. The lower 2 feet contains no pebbles and is a dark-brown fine sandy silt.

In Linn county, along Otter creek about 5 miles northwest of Cedar Rapids, in the northwest quarter of section 25, Monroe township (T. 84 N., R. 8 W.), Iowan terrace gravel is exposed in a railway cut. This cut is 25 feet deep, but the lower 10 feet is concealed by slumped material from above. The gravel becomes finer toward the surface and grades into the overburden of loess.

Iron oxide colors the different beds of gravel to various shades of buff, but in no part of the exposure does it cement the gravel. The 15 feet of highly siliceous, slightly weathered gravel that is exposed contains no carbonates. This exposure consists chiefly of sand finer than 4 millimeters in diameter within which there are only a few pebbles coarser than 2 centimeters in diameter. Analyses of size, shape, and lithology are given in No. 3 of figures 42, 43, and 44. This exposure is located within a Kansan inlier in the Iowan drift area and is covered only by Peorian loess. The loess becomes coarser with increase in depth, grading into, and in some places interstratified with the underlying sand and gravel, which shows that the two were being deposited at the same time.

Highly calcareous gravel:— In contrast to the deposits described above are those which contain a high percentage of limestone and dolomite, especially within the coarser material. These have been observed in many places within both northeastern and northwestern Iowa. In northeastern Iowa they are exposed in several places along the Upper Iowa, Turkey, Little Turkey, and Volga rivers. In these exposures the limestone and dolomite generally occur as angular platy fragments sometimes as large as 30 centimeters in average diameter and 10 centimeters in thickness. In northwestern Iowa almost all of the exposures are of this highly calcareous type, but the rocks have been rounded during transportation and seldom occur as platy fragments. The locations of the streams along which these exposures occur render it impossible for most of them to contain gravel from the Mankato ice sheet, but where Mankato gravel is in the same valley, the age must be determined on the basis of stratigraphic relationships.

An exposure of highly calcareous Iowan terrace gravel is in the southeast quarter of the northeast quarter of section 14, Westfield township (T. 93 N., R. 8 W.), Fayette county, along the north side of the Volga river at the west side of Lima. Here the gravel is exposed in a gravel pit in a terrace which is 23 feet above the stream.

The 13 feet of gravel exposed consists of a 2 1/2-foot leached zone overlying a 10 1/2-foot highly calcareous zone, the two zones having distinctly different characteristics. The limestone and dolomite which constitute about 65 per cent of the material of the lower zone give the predominating color to the mass. This is darkened to a light-gray (17"b, Cinnamon-Buff) by the additional igneous material present. The gravel is unoxidized and the only disintegration by weathering is in a few of the weaker crystalline rocks. The gravel is well stratified in horizontal beds parallel with which lie the long axes of the limestone and dolomite plates. Few of the beds are more than 6 inches thick and the only cross-bedding is of the sand and finer gravel in certain parts of these thicker beds. A mechanical analysis of average material, excluding the 10 per cent which is larger than 4 centimeters in diameter, is shown in No. 4 of figure 42. A shape analysis is shown in No. 4 of figure 43. The material larger than that represented in this analysis is almost all angular and sub-angular fragments of limestone and dolomite; the remaining rocks are igneous, generally sub-angular to curvilinear in shape. The lithology determined from an analysis of pebbles between 16 and 32 millimeters in diameter is shown in No. 4 of figure 44. The upper 2 1/2-foot zone of gravel appears to have been similar to that of the lower calcareous zone at the time of deposition, but during subsequent time, leaching processes have removed the carbonates, leaving only the non-calcareous gravel. The contraction of the beds by removal of the high percentage of carbonates destroyed the good stratification and left an unstratified mass of sand and gravel. The color of this material is darker than that of the calcareous material below because of the loss of the light-colored carbonates and a slight oxidation of the iron compounds. The gravel is overlain by 18 inches of loesslike silt, leached of its carbonates and colored by humus and iron oxide to a chocolate-brown (13'' "i, Benzo-Brown) color.

Another exposure of this type of gravel is in the northwest quarter of section 2, New Oregon township (T. 98 N., R. 11 W.), Howard county, along the Turkey river at New Oregon. Here the gravel is exposed in a terrace which stands 25 feet above the river.

This deposit is similar to that in the preceding description except that there is a lower percentage of coarse limestone.

Highly calcareous Iowan terrace gravel deposits are exposed at many places in northwestern Iowa. One of the best exposures is in a gravel pit in the east side of Sibley in the northwest quarter of section 18, East Holman township (T. 99 N., R. 41 W.), Osceola county, near the valley of Otter Creek. Here there is a wide flat area, approximately at the upland, underlain by gravel which has been exposed in several places both east and south of town. Carman[52] has described several exposures of this gravel and discussed in great detail its relations to the associated deposits. A new gravel pit, only a few yards west of the large pits which he described, exposes 20 feet of gravel.

Within this exposure the iron oxide that coats the grains colors almost all of the mass to a dark-buff (15'i, Ochraceous-Tawny) and binds the gravel together so that it will stand in a vertical section without slumping. Although the oxidation is uniform in this pit, in one nearby which was described by Carman there is considerable variation from top to bottom. In another pit about 1 1/2 miles to the southeast there is extreme variation in the amount of oxidation as well as some coloration by manganese dioxide. Disintegration of the rocks by weathering is chiefly within the gray shale which shatters readily when exposed to the atmosphere, but there is some within the less resistant igneous rocks. Leaching has not extended below the overburden and some limestone pebbles are included in its base. The gravel shows good horizontal stratification in beds varying in thickness, some reaching a maximum of almost 2 feet. Within some of these beds there is cross-bedding and lens-and-pocket structures. The cross-bedding dips at various angles within different beds, reaching a maximum of about 40 degrees. The lens-and-pocket structures generally consist of coarser or finer material and locally almost entirely of gray shale. The structure is not as distinct in this pit as in those which do not contain as much clay and iron oxide. No boulders occur within the gravel and very little gravel is larger than 10 centimeters in diameter. A mechanical analysis of the material from the coarser part of the exposure is shown in No. 5 of figure 42. The shape of the different size grades is shown in No. 5 of figure 43. The lithology of the pebbles is given in No. 5 of figure 44. This analysis shows that the pebbles

52 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 141-144, 1931.

are more than 75 per cent limestone and dolomite. The gravel is overlain by 3 feet of typical Peorian loess which is leached of its carbonates. It is colored chocolate-brown (13'' ''i, Benzo-Brown) at the top by oxidation and humus but grades into a light-buff (17'' 'd, Vinaceous-Buff) with increase in depth. There is a 1-foot gradational zone between the overburden and gravel. The gravel overlies an irregular surface of oxidized and unleached till which is probably Iowan. In certain places within this wide terrace deposit Carman has observed sections in which the gravel thins out and the loess lies in direct contact with the till.

Iowan terrace gravel is well exposed in several small gravel pits along the Little Sioux river near Cherokee. One large exposure still in operation is in the northwest quarter of section 14, Cherokee township (T. 92 N., R. 40 W.), Cherokee county. Here the gravel has been removed to a depth of about 60 feet from the upper terrace, which stands about 80 feet above the level of the river.

Oxidation has colored the gravel to medium-buff (15'i, Ochraceous-Tawny) throughout most of the section, but within some narrow seams parallel to the bedding planes, within both the coarse and the fine material, the oxidation is to a dark reddish-brown (11'k, Hazel). Leaching has removed the carbonates from the 3 to 5 feet of loess overlying the gravel, but the gravel is unleached throughout its entire thickness. Very few of the rocks have been disintegrated by weathering. Most of the gravel that is exposed in the 25-foot section above the water in the base of the pit is well stratified. Just below the overburden there is a 3-foot layer of coarse poorly sorted and poorly stratified gravel which contains large cobbles and boulders and thin beds of well-stratified fine gravel and sand. Underlying this layer of coarse gravel is a 15-foot layer of finer gravel which represents an average for the exposure. It is almost all finer than 5 centimeters in diameter but very little is finer than 1 millimeter in diameter. The well-stratified beds dip toward the south at an angle of about 8 degrees and include cross-bedding and other minor structures. Below this is another layer of coarse material which is like that at the top. It has an average thickness of 2 feet but becomes thinner at one edge. Just above the water is a 3-foot layer of sand which is well stratified. Its beds dip southward and include a large amount of cross-bedding and other minor structures. Iron oxide colors fine seams to a dark brown along the stratification lines. A mechanical analysis of the average gravel from the 15-foot layer is shown in No. 6 of figure 42. A shape analysis is shown in No. 6 of figure 43. The lithology determined from pebbles is given in No. 6 of figure 44.

Carman [58] describes the relation of these gravel deposits to the surrounding deposits in great detail and states that these gravel deposits are closely related in age to the deposition of the Iowan drift.

Intermediate type of gravel:— This group of deposits includes most of the Iowan terrace gravel. It embraces all of those deposits ranging between the two extremes previously described. In general, these deposits are found distributed throughout the entire area of northeastern Iowa and in several places in northwestern Iowa. They appear fresh with only moderate oxidation which colors the grains to various shades of buff. Leaching has removed the carbonates to a depth of 5 or 6 feet in most exposures, although in some places leaching may be either more or less.

This type of Iowan terrace gravel is exposed in several places along Black Hawk Creek. However, the best exposure is south of Holland in the southeast quarter of section 35, Colfax township (T. 88 N., R. 17 W.), Grundy county. Here it is exposed in a gravel pit within a terrace which stands 18 feet above the stream. In the 10 foot exposure there are 6 feet of gravel overlain by 4 feet of loess.

The thin coating of iron oxide which covers the grains colors the entire exposure of gravel to light-buff (15'i, Ochraceous-Tawny), but affords very little cementation or compaction. Leaching has removed the carbonates from the overlying 4 feet of loess and the upper 1 foot of gravel, below which there are many limestone and dolomite pebbles, as well as concretions of secondary lime which have been leached from the overlying beds and deposited at this lower level. The gravel is poorly sorted but deposited in distinct beds which are almost horizontal. Within these major beds is some cross-bedding, and a few clay-balls. The gravel has a low textural range, the largest pebbles observed having an average diameter of about 3 centimeters. However, most of the gravel is smaller than 1 centimeter in diameter. A mechanical separation of an average sample of the gravel is shown in No. 7 of figure 42. The percentage of rounding is shown in No. 7 of figure 43. A lithologic analysis of pebbles is shown in No. 7 of figure 44. The

[58] Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, pp. 153-154, 1931.

4-foot deposit of loess overlying the gravel is oxidized to the usual buff (17" 'i, Buffy-Brown) color of loess, and leached of its carbonates. At one place in the exposure there are pebbles scattered through the lower 10 inches of the loess and slight stratification in the lower 6 inches. This suggests that the loess and gravel were deposited in close succession.

In an extensive terrace about 22 feet above Dry Run, in the southeast part of Cedar Falls, there are several exposures of Iowan terrace gravel. The best exposure is in the northeast quarter of section 13, Cedar Falls township (T. 89 N., R. 14 W.), Black Hawk county. This exposure shows 13 feet of gravel overlain by 2 to 3 feet of loess-like silt.

Iron oxide coating the grains has colored most of the deposit to light-buff (15'i, Ochraceous-Tawny), although different colors within separate beds and lenses of the exposure range from grayish-buff (17"b, Cinnamon-Buff) to medium-buff (17"i, Tawny-Olive). Leaching has removed the carbonates from the overburden and gravel to a depth of 4 feet, and weathering has disintegrated some of the weaker crystalline rocks. The gravel is well stratified in almost horizontal beds, but in some places these beds contain considerable cross-bedding and many lenses and pockets. Aside from several boulders between 35 and 45 centimeters in diameter, the maximum size of the coarse gravel is between 3 and 6 centimeters in diameter. Almost all of the material consists of sand and fine gravel such as is shown in the mechanical analysis of No. 8 of figure 42. The percentage of rounding of each size grade is given in No. 8 of figure 43. The rock content is shown in No. 8 of figure 44. There is a slight gradation between the gravel and the overlying loesslike silt. The overburden is colored chocolate-brown (17" ', Wood-Brown) by iron oxide and humus.

In the southwest quarter of the northwest quarter of section 6, Paris township (T. 97 N., R. 12 W.), Howard county, Iowan terrace gravel is exposed along Crane Creek 6 miles east of Elma, in a terrace which stands 24 feet above the stream. This exposure represents an average of the exposures along this stream in the southern part of Howard county.

The gravel is colored to a light-buff (15', Ochraceous-Tawny) by the iron oxide which coats the grains. Leaching has removed the carbonates to a depth of 5 feet including the 1 foot of overburden. The well sorted gravel shows good horizontal stratification, interrupted by cross-bedding and lens-and-pocket structures. The material consists chiefly of sand and fine gravel with only about 12 per cent larger than 8 millimeters in diameter. There is also coarser gravel which has a maximum diameter of about 5 centimeters, and in addition to this there are about 20 boulders in the bottom of the pit which average about 15 centimeters in diameter. The percentage of each size grade as determined by a mechanical analysis of the average gravel is shown in No. 9 of figure 42. The percentage of rounding is shown in No. 9 of figure 43. The lithology is shown in No. 9 of figure 44. The overburden is loesslike silt which is between 1 and 2 feet thick. Pebbles are scattered through it and increase in number toward its base. It is colored chocolate-brown (13" "i, Benzo-Brown) by iron oxide and humus. The material underlying the gravel was not exposed in this section, although in another exposure farther down stream oxidized and unleached till was exposed at the base of the gravel.

The Relations of the Gravel

Terraces of Iowan gravel are along almost every stream, large and small, within the Iowan drift areas. In those valleys extending across the Iowan drift area and into the Mankato drift area the water from the melting Mankato ice carried sand and gravel which also was deposited in these valleys. Besides the Mankato and Iowan gravels, Loveland gravel may also be present, representing deposition in these pre-Iowan valleys before the advent of the Iowan ice. It is possible for gravel of all three of these ages to occur within the same valley.

The characteristics of the gravels of the Loveland, Iowan, and Mankato ages are so similar within northwestern Iowa that in many places it is difficult to distinguish one from the other. The only accurate basis upon which these deposits can be differentiated is that of their relationship to other materials.

During the interval following the formation of the gumbotil on the Kansan drift and before the advance of the Iowan ice, the Kansan drift surface underwent erosion which developed a complete drainage system. In the valleys developed, the Loveland gravel was deposited. Loveland gravel was more extensive in northwestern Iowa than in northeastern Iowa, because of the more extensive erosion which the area had undergone. In fact, the presence of Loveland gravel in northeastern Iowa has never been proven. This period of erosion continued until the advance of the Iowan ice which deposited its load on the fresh erosional and depositional surfaces.

Streams flowing down these valleys during the advance of the glacier might either deposit their load on top of the underlying Loveland deposits or, if the volume of water was large enough might rework the Loveland deposits and incorporate them with those of Iowan age. In neither case, however, would there necessarily be a distinguishable break between these deposits.

If the streams continued to flow down these valleys during the time that the area was covered by ice, then sedimentary processes were continuous throughout all the time that the ice was present. This seems highly improbable, however; instead the glacier may have removed some of these deposits left in front of the advancing ice, incorporating them in its load of detrital material. In either case, as the ice melted the deposition in the valleys would either be on the surface of the previously deposited gravel or the Iowan till, or it would rework the underlying deposits, forming one new deposit. Hence the deposition of Loveland and Iowan could be either continuous or separated by Iowan till, glacial erosion, or even weathered zones. Or, as stated above, the gravel in the valleys before the advance of the Iowan ice might have been reworked and incorporated into that deposited as the ice retreated.

In those valleys which crossed the Iowan drift area and headed up in the Mankato drift area, a problem similar to the one between the Iowan and Loveland deposits is involved. The streams flowing from the melting Mankato ice carried a vast amount of material which was deposited along the valleys as was the Iowan gravel. Thus in all of these valleys it is possible to have gravel of two ages, the Loveland and the Iowan, and in some valleys the Mankato gravel may also be present.

Since the gravel was deposited the streams have entrenched themselves in these wide, flat areas leaving the remnants as terraces. In northeastern Iowa, within the Iowan drift area, the terraces range from almost the level of the present stream to about 30 feet above the stream, but beyond the Iowan drift margin some of the terraces are as high as 50 to 75 feet above the level of the stream. The Iowan terraces of northwestern Iowa have a wider range in height above the streams. This fact is well illustrated by Carman [54] in his discussion

54 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Vol. XXXV, pp. 157-166, 1931.

of the valley gravels. Near the heads of some of the valleys within the Iowan drift area, the terraces are almost at the stream level, while some terraces such as those along the southern part of Waterman Creek, also within the Iowan area, are more than 100 feet above the level of the stream.

Terraces along those streams which did not carry drainage from the Mankato ice must be either Iowan or Loveland. In some, it is impossible to exclude the possibility that the Loveland deposits are deeply buried or reworked and incorporated in the Iowan deposits. However, in some exposures the gravel overlies oxidized and unleached till which appears to be Iowan in age, and in others it overlies leached Loveland silt. In most of the exposures the gravel extends below the ground water surface, thus eliminating the possibility of observing its relationship to older deposits. Contacts along the sides of the exposures are few, since the gravel deposits are so extensive that only the coarser and more valuable material is removed and the exposures do not crowd the margin of the terraces where the overburden is generally thicker.

Iowan gravel can be definitely differentiated from the Mankato gravel when it is directly related to the Iowan till or covered by Peorian loess. The loess is extremely important in correlation, since it is pre-Mankato in age. Besides loess, the gravel is covered by loess-like silt within which pebbles are sparsely distributed, generally in increasing numbers toward the base. Both of these types of overburden sometimes show a gradational zone between them and the gravel.

The Age of the Gravel

Early investigators believed the Iowan terrace gravel to have been deposited during the retreat of the Kansan glacier, and called them the valley phase of the Buchanan.[55] Not until after 1910 were they referred to as Iowan terrace deposits.

These gravel deposits are in valleys eroded in the Kansan drift during the post-Kansan gumbotil pre-Iowan interval and could not be Kansan in age. In some places they are observed overlying and interbedded with Iowan till; here they were either deposited simultaneously with or following the deposition of the till. The overburden of loess which is immediately post-Iowan in age grades into the gravel

[55] Calvin, Samuel, Geology of Howard County: Iowa Geol. Survey, Vol. XIII, pp. 67-68, 1903.

in some exposures, which shows that the loess was being deposited during the last stages of gravel deposition.

The age of the gravel of these terrace deposits cannot in all cases be so closely determined as in those mentioned. Where the underlying material is not exposed, as is generally the case, the deposit may also include gravel of Loveland age, gravel deposited as the ice advanced, or even both. If so, the older material was probably reworked and redeposited during the retreat of the Iowan glacier.

THE MANKATO GRAVELS

The hemi-eliptic lobe of the late Wisconsin glacier (the Mankato) extended into Iowa as far south as Des Moines, which is a distance of 140 miles. Where it crossed the Iowa-Minnesota line the width of the lobe was about 135 miles, the east margin crossing in the east side of Worth county near Northwood, and the west margin crossing in Osceola county, north of Sibley (see figure 2).

The surface of the Mankato drift is generally a flat or gently undulating plain except for the more or less well-developed constructional terminal moraine topography and moundlike hills and depressions on the ground moraine surface. The drainage is youthful, and undrained lakes and marshes are numerous. Most of the streams are in broad swales and have developed only the small narrow channel in which they flow, the larger valleys being the partly filled remnants of an older drainage system. Some of the larger streams have cut deep, narrow valleys in the Mankato drift plain, but even these streams have formed the topography of only a small part of the area they drain.

As the Mankato ice melted, gravel was deposited in two general positions as were the Iowan gravels: (1) as irregular masses of gravel within the till and as kamelike knobs standing above its surface; and (2) as outwash in the valleys in front of the ice margin. These two types of deposits will be discussed separately, since they differ in practically every aspect.

THE MANKATO UPLAND GRAVEL

The Distribution of the Gravel:

The Mankato upland gravel is distributed throughout the area of Mankato drift as shown in figure 46. Most of the exposures are either near the drift margin within what has been called the terminal moraine

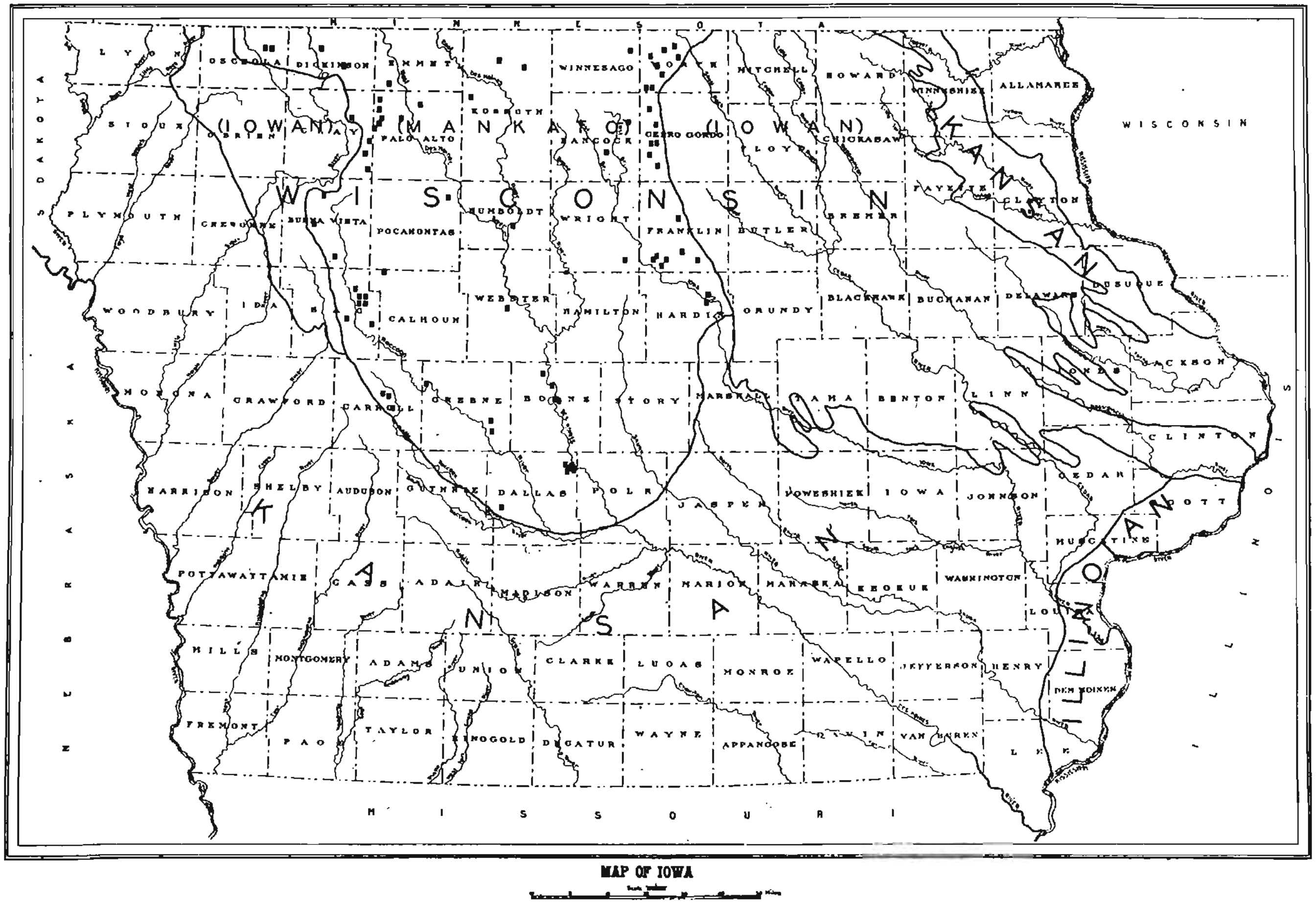


FIG. 46. — The squares show the locations of Mankato upland gravel exposures within Iowa.

or within groups distributed over the drift surface as recessional moraines. Within the moraine areas, both terminal and recessional, the deposits are generally small. One notable exception is Ocheyedan mound, which stands 150 feet above the valley bottoms and covers an area of about 40 acres. Other exposures of gravel, both within and outside of the terminal and recessional moraines areas, occur as irregular masses within the till; some are buried deeply and others are close to the surface.

The locations of the exposures represented in figure 46 show that the deposits are unevenly distributed throughout the drift area. There are other exposures within this area from which the gravel has been removed and which are now concealed by slumped material. Still other masses of gravel have never been opened, because of excessive thickness of overburden, low commercial value, or the lack of demand for the gravel; the last is caused by the abundance of the easily available and uniform-textured valley gravel deposits along most of the streams.

The Characteristics of the Gravel

General Characteristics:

The Mankato upland gravel was deposited during the melting of the Mankato glacier and the deposition of the till. The exposures of this type which were studied show gravel deposited as irregular masses deep within the till, as lenses and thin beds interstratified with the till, as irregular masses just below the surface of the till, and as deposits in kamelike hills which stand above the surface of the till.

The Mankato drift, of which the Wisconsin upland gravel is a part, represents deposition by the last ice invasion and consequently is not overlain by younger deposits. Since it occupies a position at the surface it has been subjected to weathering processes during all subsequent time. These have leached the carbonates from the till to an average depth of between 2 and 3 feet, and have oxidized the iron compounds still deeper. Thus the till can be divided into three zones on the basis of weathering: the upper zone of oxidized and leached; next, the oxidized but unleached; and below this the fresh unaltered till. The period of weathering has not been sufficiently long to form gumbotil at the till surface.

Where gravel instead of till occupied a position within the zone of weathering, it underwent changes comparable to those in the till.

Leaching has removed the carbonates from the gravel and overburden to a combined depth of 2 to 3 feet, below which there are both primary and secondary carbonates. The secondary carbonates form lime concretions, but it is very unusual that they cement the gravel into a conglomeritic mass.

The coloration of the gravel by iron oxide varies both within single exposures and with different exposures. Some exposures appear fresh, uncolored by oxidation except possibly within narrow bands which are generally along bedding planes. Other exposures are colored dark-buff (15'i, Ochraceous-Tawny) throughout most of the gravel but in places contain beds of gray unoxidized gravel interstratified with that which is oxidized. Still others contain beds or irregular masses of gravel which are colored dark reddish-brown (11'k, Hazel) and are firmly cemented by iron oxide. In addition to the many shades of brown and buff produced by the iron oxide, in a few exposures thin layers along bedding planes and irregular masses are colored black by the manganese dioxide which coats the grains and in some places cements them together.

The general structure of the gravel is very irregular. Much of it is in horizontal beds within which are minor irregularities such as cross-bedding, lenses, pockets, clay-balls, steeply dipping beds, and boulders. In some parts of the exposures the gravel is unstratified and poorly sorted.

There is a wide size range within these gravel deposits. The greatest percentage of gravel is smaller than 5 centimeters in diameter, but cobbles and boulders as large as 75 centimeters in diameter are common. The percentage of each of the different size grades, determined by a mechanical analysis of samples of average material from different exposures, is shown in figure 47. The percentage of rounding of the size grades between 1/16 and 32 millimeters in diameter is shown in figure 48. Rock analyses of pebbles between 16 and 32 millimeters in diameter are shown in figure 49.

The material overlying this gravel is either Mankato till or loesslike silt. The till is generally less than 3 feet thick but in one exposure observed it was 25 feet thick. The loesslike silt observed was not thicker than 3 1/2 feet and was generally less than 2 feet. In both types of overburden weathering has developed the zones previously mentioned. They are leached to a depth of from 2 to 3 feet where unaffected by subsequent erosion. However, oxidation extends much deeper and

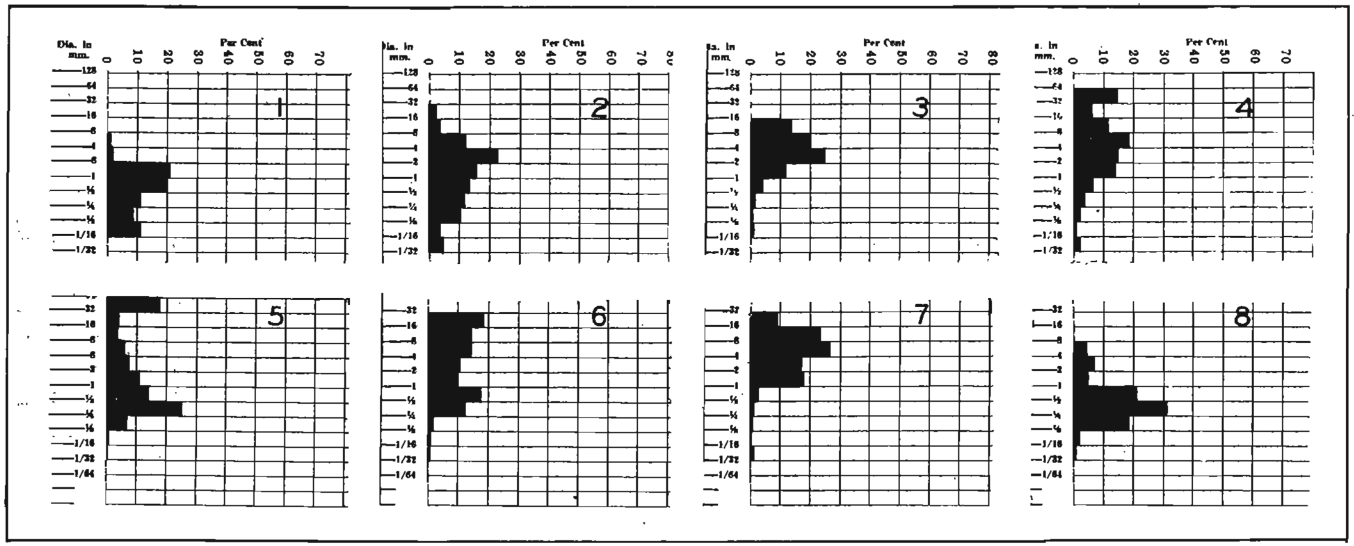


FIG. 47. — Graphs showing mechanical analyses of Mankato upland gravel. The numbers of these analyses correspond with those of figures 48 and 49.

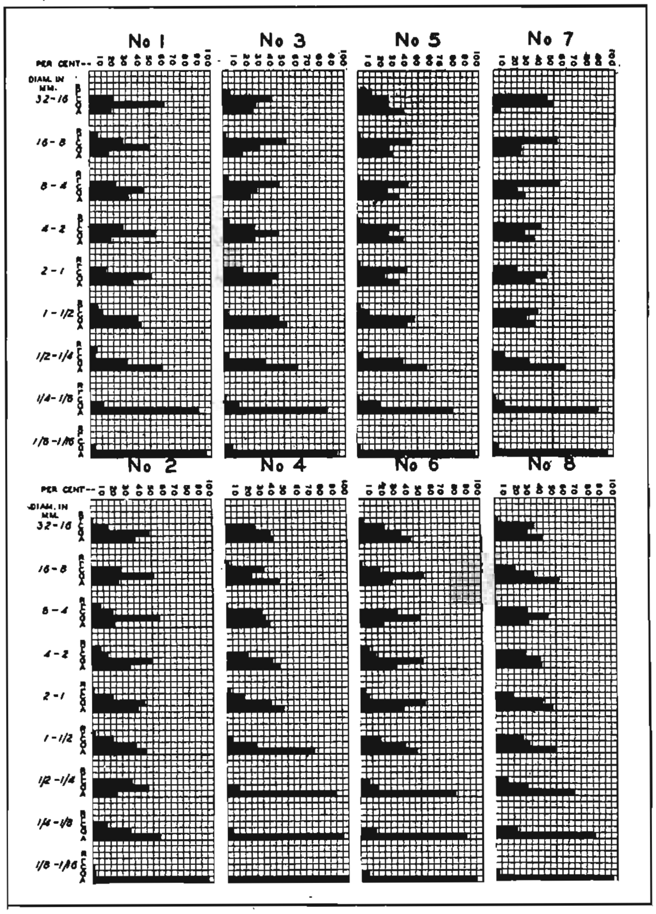


FIG. 48. — Graphs showing shape analyses of each size grade between 1/16 and 32 millimeters in diameter of Mankato upland gravel. The numbers of these analyses correspond with those of figures 47 and 49. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

colors the overburden dark-buff (17'' 'd, Vinaceous-Buff). The addition of humus colors the soil zone to a darker shade of brown (13'' ''i, Benzo-Brown) than the normal oxidized material.

Characteristics of Exposures

Almost all of the exposures are in gravel pits which have been used during recent years to obtain road surfacing material. One of the most typical exposures in the northeastern part of the Mankato drift area is in Worth county. It is in the southwest quarter of section 27, Hartland township (T. 100 N., R. 21 W.), along the north side of

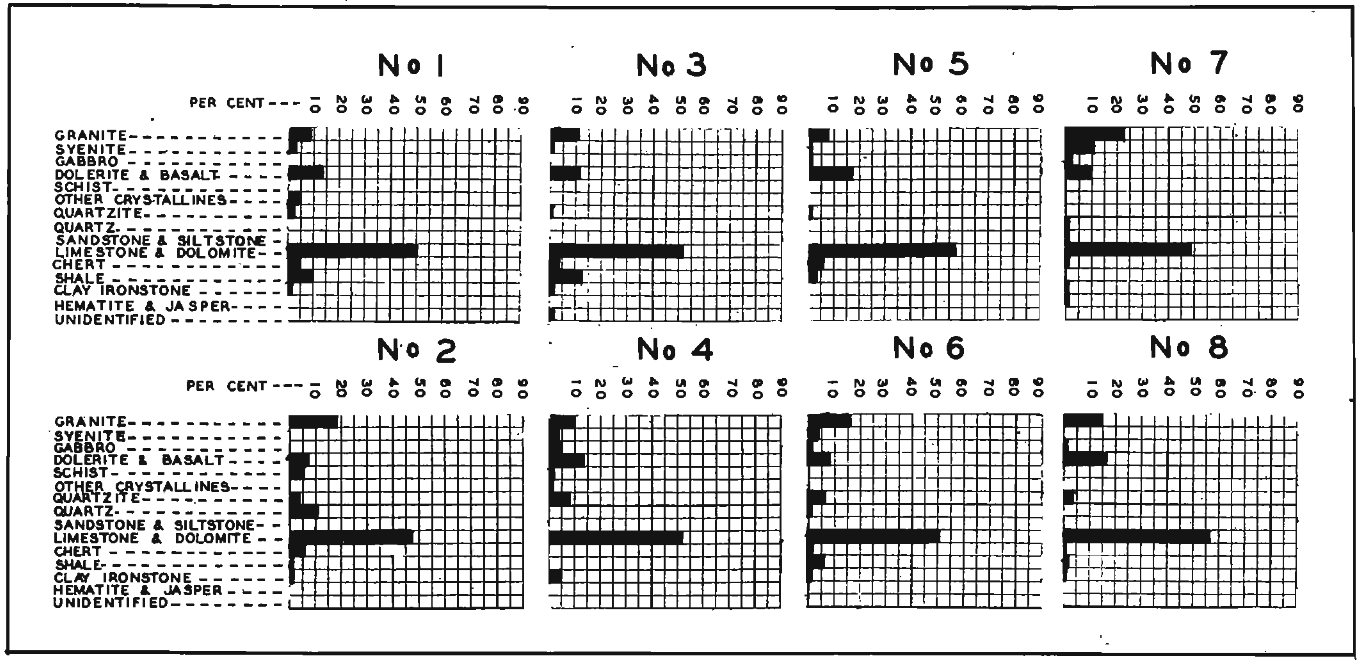


FIG. 49. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter. The numbers of these analyses correspond with those of figures 47 and 48.

primary No. 105, west of Northwood. Here the gravel occurs in a kame on the surface of the Mankato drift. This is within the terminal moraine area and represents only one of the many kames within this area.

The gravel is gray (17"b, Cinnamon-Buff) and shows no oxidation except in the thin gradational zone between it and the overburden. This zone is colored light chocolate-brown (17"', Buffy-Brown) by the fine material from the overburden. In one part of the pit the overburden is only 16 inches thick and leaching extends 1 foot into the gravel, making the total depth of leaching 28 inches. A few of the rocks, especially coarse crystalline ones, have been disintegrated along their margins by weathering so that they crumble readily with slight pressure. However, all of the gravel appears fresh. The central part of the pit is composed chiefly of well-stratified sand and gravel which is practically all smaller than 3 centimeters in diameter. Within these beds are various minor irregularities such as cross-bedding, lens, and pocket structures. Toward the margin the gravel becomes coarser, containing some cobbles as large as 20 centimeters in diameter. It is poorly stratified in some places and in others it is a heterogeneous mass. A few boulders, the largest 40 centimeters in diameter, are scattered sparsely throughout both coarse and fine gravel. The percentage of each size grade of a sample of average material is shown in No. 1 of figure 47. The percentage of rounding is shown in No. 1 of figure 48. The rock content is given in No. 1 of figure 49. The overburden is sandy silt that is colored by humus and oxidation of the iron compounds to chocolate-brown (13" "i, Benzo-Brown) in the upper 15 to 24 inches below which it is lighter colored. Pebbles are scattered throughout the overburden. No contacts at the base of the gravel were exposed, although the pit extends down more than 4 feet below the general surface of the drift plain.

Another exposure of the Mankato upland gravel is in the southeast quarter of section 5, Bristol township (T. 99 N., R. 22 W.), Worth county, along primary road No. 105, near the west side of the county. Here the gravel occurs in a pit which is in an elongate ridge that resembles an esker. This ridge is on the hummocky surface of the ground moraine and has a general northwest-southeast elongation. Since the pit has not been worked for several years, the slumping of overlying material has covered most of the exposure.

Within the gravel mass the oxidation of the iron compounds is very slight. The gravel is gray (17"b, Cinnamon-Buff), but the large number of small clay-balls included in the gravel are buff colored, giving a light-buff tint to the entire mass. Leaching has removed the carbonates from the 2 feet of overburden and from the upper 6 to 10 inches of the highly calcareous gravel. The gravel is poorly stratified and contains some cross-bedding. There are a few large boulders in the bottom of the pit which are residual from either the gravel removed or the overburden, but aside from these the material is practically all smaller than 3 centimeters in diameter. The percentage of each size grade is shown in No. 2 of figure 47. The percentage of rounding is shown in No. 2 of figure 48. A rock analysis of pebbles is shown in No. 2 of figure 49. In the base of the pit is a resistant ridge of gravel, colored dark reddish-brown (11'k, Hazel) and cemented into a firm conglomeritic mass by iron oxide. Closely associated with the reddish-brown beds are some beds colored black by manganese dioxide and similarly cemented, forming part of the resistant material of the masses. The material forming the resistant ridge is highly calcareous and lithologically the same as the rest of the gravel exposed. There seems to be no doubt that this represents cementation of the Mankato gravel and that it is not part of an older deposit on which the later Mankato gravel was deposited. This conclusion is further substantiated by another exposure of gravel in this same elongate hill about 30 rods southeast of the one just described, in which the same type of highly cemented material is exposed. This type of cementation has been observed in three other Mankato upland gravel exposures within this part of the state, but in none of the others was it as well developed. The overburden here is about 2 feet thick, colored to the usual chocolate-brown by humus and iron oxide, and leached of its carbonates. No material underlying the gravel was exposed.

In Hardin county, about 6 miles southeast of Iowa Falls, in the southeast quarter of the southwest quarter of section 36, Hardin township (T. 89 N., R. 20 W.), a gravel pit exposes 9 feet of Mankato upland gravel. This gravel is an irregular mass inclosed in the till and covered by only about 18 inches of overburden. This is within a region of considerable relief along the Iowa river near the margin of the Mankato drift.

The gravel is gray (17" 'b, Avellaneous), and the only coloration by iron oxide is within the gradational zone between it and the light chocolate-brown colored overburden. Leaching has removed the carbonates to a depth of about 27 inches including the 18-inch layer of overburden. The material consists chiefly of gravel finer than 2.5 centimeters in diameter and coarse sand. The percentage of fine sand is low. Only 4 cobbles and boulders were found in the base of the pit, but in a similar pit a short distance away the cobbles and boulders were abundant within the finer gravel and sand. The stratification is good throughout the exposure. Within the thick strata cross-bedding and lenses of coarser gravel and finer sand are common. The percentage of each size grade is shown in No. 3 of figure 47. The coarser sand and gravel, as in the other exposures of this type, show little rounding by stream action, and some of the pebbles have striated surfaces. A shape analysis is shown in No. 3 of figure 48. The rock content is shown in No. 3 of figure 49. The overburden is loesslike sandy silt, which has been leached of its carbonates. A few pebbles scattered throughout the 18-inch layer increase in number toward the top of the gravel. It is colored medium chocolate-brown (13'' ''i, Benzo-Brown) at the surface by humus and iron oxide, but grades into a light chocolate-brown (17'' 'i, Buffy-Brown) toward the top of the gravel because of the decrease in the amount of humus.

One of the most conspicuous glacial topographic features of northwestern Iowa is the Ruthven terminal moraine which extends from south of the town of Ruthven into southern Minnesota. It has a typical terminal moraine topography with a relief of 50 to 100 feet. The small hills are generally steep sided and show gravel at their tops and sometimes along their sides. Swamps and small lakes are common in the lowland areas. Gravel has been exposed in many places throughout this morainic area, but most of the exposures have since been concealed by slumping of the overlying material.

An exposure of this gravel is about 1 1/2 miles east of Ruthven, near the center of the north side of section 21, Highland township (T. 96 N., R. 34 W.), Palo Alto county, in the Ruthven morainic area. The gravel is on a flat upland but does not form a kamelike knob.

The material consists primarily of sand and fine gravel. Not more than 10 per cent of the entire mass is larger than 6 millimeters in diameter. Three boulders between 22 and 35 centimeters in diameter were found about the base of the pit. All of the sand and gravel is well stratified in almost horizontal, wavy beds. However, cross-bedding and lens-and-pocket structures make up practically all of some of the beds, especially those toward the base of the pit. In the main face of the exposure a fault with a vertical displacement of about 8 inches extends from top to bottom. The structure and general characteristics of the gravel exposed are shown in figure 50. The section exposed is as follows:

	Feet	Inches
6. Overburden: loesslike silt containing only an occasional pebble; leached, colored chocolate-brown (13″″i, Benzo-Brown) by iron oxide and humus, unstratified; grades into similar material containing a much greater percentage of pebbles, and lighter brown color (17″′, Wood-Brown) from oxidation alone	2	3
5. Gravel: light-brown (17″i, Tawny-Olive) leached only in the upper part; consists of interbedding of sand and fine gravel. Gravel beds are generally 1 to 2 inches thick and sand beds about 6 inches thick; neither is of uniform thickness over any horizontal distance and they often represent large thin lenses. Cross-bedding dipping toward the southwest is present in the sand	5	
4. Gravel: interbedding of coarse and fine material. The coarse material is almost all smaller than 5 centimeters in diameter and only a low percentage is larger than 2 centimeters in diameter; beds of coarse gravel are about 5 inches thick, fairly continuous throughout the exposure, horizontal but slightly wavy. Some lens-and-pocket structures; cross-bedding is distinct within the finer gravel and sand beds	6	
3. Sandy silt: bed 6 to 10 inches thick, generally continuous but lenses out along the margins; contains no coarse material; beautifully stratified with a fine delicate structure consisting essentially of cross-bedding, lens-and-pocket structures		10
2. Gravel and sand: chiefly sand, including fine stringers of fine gravel; structure essentially cross-bedding, lenses, and pockets which dip generally toward the southwest. In the upper one foot of this zone the material is chiefly in horizontal beds within which are few irregularities such as cross-bedding, lens-and-pocket structures. Interbedded with this are beds of finer gray sand, sometimes colored dark-brown by iron oxide. The coloration is parallel to the stratification	6	
1. Gravel: coarser than the rest of the exposure; upper and lower 3-foot members are medium coarse gravel while the middle 1-foot member is coarse. Stratification is poor, especially in the middle member. Some material is as large 20 centimeters in diameter and much of it larger than 8 centimeters in diameter	7	

A mechanical analysis of the average material of zone No. 4 of the above section is shown in No. 4 of figure 47. The shape is shown in No. 4 of figure 48. A rock analysis is shown in No. 4 of figure 49. In the coarser material of the pit, reddish-pink quartzites are abundant.

Another exposure of Mankato upland gravel is in a gravel pit in the southwest quarter of section 2, Jackson township (T. 88 N., R. 36

FIG. 50. — Exposure of Mankato upland gravel.

W.), Sac county, about 3 miles north of Sac City. This exposure is within 6 miles of the Wisconsin drift margin. It is an irregular mass of gravel entirely enclosed within Wisconsin till. The exposure is 19 feet deep.

The gravel of the entire exposure appears fresh, colored only slightly (17" 'b, Avellaneous) by iron oxide. Leaching has removed the carbonates from only the upper 2 feet of the overburden, the underlying gravel containing an abundance of limestone and dolomite. The gravel is well stratified in beds which dip toward the south and southeast at an angle of about 35 degrees. Some cross-bedding and lens-and-pocket structures are found in the major beds, but only in small amounts in comparison with other pits of this type. Most of the gravel is fine, as is shown in the mechanical analysis No. 5 of figure 47. The coarser gravel forms thin stingers through the finer material. All of the gravel exposed in the east side of the pit is slightly coarser than that of the west side. Only 11 boulders, between 25 and 40 centimeters in diameter, are in the bottom of the pit. Some of these probably came from the Wisconsin till which overlies the gravel. All of these boulders are angular, showing no rounding along the sharp fractured edges. The percentage of rounding is shown in No. 5 of figure 48. The lithology of pebbles is given in No. 5 of figure 49. The overburden ranges in thickness from 2 to 9 feet. It is Wisconsin till covered in a few places by loesslike silt. The thickness of the overburden varies, because of the irregular surface at the top of the gravel. It is leached to a depth of about 2 feet. Oxidation has colored it to a light-buff (19"i, Isabella Color) and by addition of humus the upper soil zone is darker brown (17" ', Wood-Brown).

Mankato upland gravel is exposed in the northeast part of Dallas county on the surface of the Mankato drift about 20 miles from its most southern margin in Iowa. Here in a hummocky morainic topography the gravel deposits are exposed in and near the tops of several hills. The best exposure is in the northwest quarter of section 23, Grant township (T. 80 N., R. 26 W.), about 3 miles southwest of Granger.

The coloration of the gravel varies throughout the pit. Most of it is only slightly colored by iron oxide to light-buff (19"i, Isabella Color) but certain beds are much darker brown. At the base of the 20-foot exposure the gravel is colored grayish-green, and is immediately overlain by about 16 inches of rusty-brown (15'i, Ochraceous-Tawny) gravel. This in turn is ovelain by a 6-inch layer of gravel colored black by manganese dioxide. Leaching has removed the carbonates to a depth of about 30 inches, almost all of which is within the overburden. The structure of the gravel of this section is quite irregular. In one part of the pit the gravel is well stratified in horizontal beds, but the remainder is practically an unstratified heterogeneous mass. In some places the poorly stratified material resembles beds which have slumped following deposition. Clay-balls and inclusions of till are common throughout the exposure. The gravel shows a wide size range, from till and fine sand to boulders 25 centimeters in diameter. Many of the cobbles between 12 and 18 centimeters in diameter are scattered throughout the gravel. However, the material smaller than these cobbles is almost all smaller than 3 centimeters in diameter. A mechanical analysis of this fine material is shown in No. 6 of figure 47. The percentage of rounding is shown in No. 6 of figure 48. A rock analysis of pebbles is shown in No. 6 of figure 49. The overburden is from 2 to 2 1/2 feet thick. It is loesslike silt, throughout which small pebbles are sparsely scattered. Leaching has removed the carbonates and oxidation of the iron compounds colors the overburden medium-brown (17'' ', Wood-Brown) in the lowest part, and in the soil zone above it is colored darker brown (13'' ''i, Benzo-Brown) by the addition of humus.

Several exposures of Mankato upland gravel are in gravel pits along the northeast side of the Des Moines river about 1 mile southwest of Boone, in Boone county. These exposures represent irregular masses of gravel buried deep within the Mankato drift. In addition to these exposures, there are several in which small masses or lenses of gravel only a few feet in diameter are included within the till.

Along the west side of primary road No. 30, in the extreme northwest quarter of section 31, Des Moines township (T. 84 N., R. 26 W.), Boone county, the gravel is exposed in three gravel pits. In two of the pits very little can be seen, as they have not been worked for several years. In the other pit 40 feet of gravel is exposed, overlain by 25 feet of Mankato till (see figure 51).

FIG. 51. — Exposure of Mankato upland gravel covered by a thick layer of Mankato till.

The gravel is colored to medium-buff (17''i, Tawny-Olive) by the small amount of iron oxide coating the grains and by the high percentage of limestone, dolomite, and chert which is present. Along some of the bedding planes a thin seam of gravel is colored black by manganese dioxide which coats the grains and sometimes forms a weak cement. All of the gravel is highly calcareous. The entire section is well stratified in horizontal beds ranging in thickness from less than 1 inch to more than 1 foot. Cross-bedding, lenses and pockets occur within some of the horizontal beds. The clastic texture of the gravel is quite uniform throughout the pit. Aside from a few boulders, practically all of the gravel is smaller than 2 centimeters in diameter. It has been reported that at its base the gravel lies on a conglomerate of boulders and fine light-gray sand. A mechanical analysis of a sample of average gravel is shown in No. 7 of figure 47. The percentage of rounding is shown in No. 7 of figure 48. The only observed relationship of the gravel to surrounding material is to the overlying till, which is 25 feet thick. Since this exposure is along a steep slope the oxidation and leaching are not to uniform depths. Leaching extends to a depth of more than 4 feet in the till and the oxidized zone to a depth of more than 17 feet. The lower 8 feet of the till overlying the gravel is neither leached nor oxidized although the underlying gravel does show oxidation. There is no gradation from the gravel into the overlying till. The two are separated only by a 6-inch bed of sand containing clay and fine material. The upper surface of the gravel shows no indication of being plowed up by the glacier which passed over it and deposited the overlying Mankato till.

Two more gravel pits occur east of primary road number 30, along the northeast side of the Des Moines river, a short distance east of the exposure just described. In the west one of these two pits the gravel is overlain by fresh, unleached and unoxidized Mankato till which in turn is overlain and interbedded with stratified sand and silt in which the laminae have a maximum thickness of 1/2 inch. In some places the sand is in pockets several inches thick but becomes thin along the margins. This zone of interbedded till and sand and silt is overlain by distinct till. In the other pit the sequence is the same as that just given but not as distinct.

Relations of the Gravel

The relationship of the Mankato upland gravel to the associated materials and the topography is shown in several exposures. Some of these relationships were described at the same time the characteristics of the gravel were discussed. The exposures show the gravel as irregular masses which may be either deep within or near the surface of the till, as kamelike hills or eskerlike ridges on the surface of the till, as irregular masses included within till of kamelike hills, and as lenses and thin beds interbedded with till.

In the northwest quarter of section 31, Des Moines township (T. 84 N., R. 26 W.), Boone county, Mankato upland gravel is exposed in three gravel pits as irregular masses buried deeply within the Mankato till. In only one, however, are the relations to the till exposed. In it the gravel is 40 feet thick, unleached of its carbonates but colored some by oxidation. Overlying the gravel is 25 feet of Mankato till, leached and oxidized in the upper part, below which it is unaltered. No distinct gradation separates the gravel from the overlying till. The nearest approach to this is a thin bed of well-stratified sand containing considerable clay. Otherwise the break between them is a distinct line. The upper surface of the gravel appears just as deposited, undisturbed by the movement of an overriding ice sheet which deposited the 25 feet of overlying till.

East of the primary road number 30, only a short distance from the exposures just described, are two gravel pits which have not been worked for several years. Their relations to the Mankato till are the same as those described in the preceding section. However, overlying this gravel there is an interbedding of well-stratified beds and lenses of sand and silt with the till. The relations, the structures, and the shapes of these deposits show that they represent primary deposition in their present position. Furthermore, none of them show signs of having been disturbed by overriding ice action. Several small irregular masses of oxidized but calcareous gravel only a few feet in diameter and completely surrounded by unaltered Mankato till are exposed in cuts within this same vicinity.

In the northeast part of Dallas county, in the east central part of Grant township (T. 80 N., R. 26 W.), there are several exposures of Mankato gravel, all in or near the tops of the hills. The gravel exposed is calcareous below the 2- to 3-foot leached zone in the overburden and gravel. Mankato till has been observed along the sides and below the gravel, but the overburden is loesslike silt that contains pebbles which become more numerous toward the surface of the gravel. One of the best exposures in which to observe these relations is in the northwest quarter of section 23. Many other deposits distributed throughout the Mankato area show these same relations to the Mankato till. Some of the best areas in which they can be observed are in Palo Alto county, in the western part of Worth and Cerro Gordo counties, and in the southwest part of Franklin county.

Within the Mankato area there are large kamelike hills in which gravel is contained within the Mankato till. One of these is Ocheyedan Mound, in the southwest quarter of section 12, Ocheyedan township (T. 99 N.; R. 40 W.), in the northeast part of Osceola county. In this mound which stands about 150 feet above the main drainage lines, and conspicuously above the surrounding topography, two gravel pits have been opened. One of the pits is near the top and the other is along the north slope; both show sand and gravel. Another mound, similar to the Ocheyedan Mound, is Pilot Knob, in the extreme northeast part of Hancock county, Ellington township (T. 97 N., R. 23 W.), in sections 3 and 4. In it several sand and gravel masses, surrounded by Mankato till, are exposed.

Small kamelike hills are abundant in the morainic areas on the Mankato drift. These small hills consist of till and gravel, although some are almost entirely gravel, covered by a thin veneer of till or loesslike silt. Good exposures of this type may be observed in many places throughout the Mankato drift area, especially within the terminal moraines. One is in the southwest quarter of section 27, Hartland township (T. 100 N., R. 21 W.), Worth county. Many similar kames occur in this same area within Worth and Cerro Gordo counties.

An exposure of gravel in an eskerlike ridge has been described in the northeast quarter of section 5, Bristol township (T. 99 N., R. 22 W.), Worth county. This ridge stands above the ground moraine plain close to the margin of the terminal moraine. It is slightly sinuous and varies in height from place to place, finally merging into the ground moraine surface. At the location of the above exposure the ridge was higher, thus forming a kamelike knob. The trend of the ridge is in a southeast-northwest direction. The gravel is covered by a thin layer of silty till-like material where observed near the top of the ridge, and a thicker typical till along the flanks. No gradation from one into the other was observed. The base of the gravel is below the ground water surface; thus no contact with underlying material was exposed.

The Age of the Gravel

The characteristics and relations of the Mankato upland gravel show them to be closely related in age to the till. Those deposits entirely inclosed within Mankato till must have been deposited at the same time the till was being let down from the melting ice. Some small masses may have been picked up in a frozen condition from the overridden surface by the advancing glacier and deposited as gravel boulders within the till. The irregular masses of gravel at the surface of the till and the kamelike hills on the surface of the till may have been deposited either at the same time as the associated till or as outwash at the margin of the melting ice.

MANKATO TERRACE GRAVEL

Distribution of the Gravel

Mankato terrace gravel deposits are distributed widely throughout much of the northern part of the state both within and beyond the Mankato drift area, but, as stated under the discussion of the Iowan terrace gravel, they can be differentiated from the older gravels, the Iowan and Loveland, which were probably deposited in most of the valleys only by their relations to associated materials. This being true, only those deposits within the drift area will be included here; the others are described as undifferentiated gravel. The distribution of the gravel deposits within the Mankato drift area is shown in figure 52.

The Mankato terrace gravel deposits within the Mankato drift area occur along almost every stream, regardless of size, and extend practically to its head. The present stream channels are cut in these valley fillings, while the parts which remain form terraces which vary greatly in height, some being as much as 120 feet above the stream. In places, small patches of gravel along the valley wall are all that remain of these gravel deposits; but more commonly the terraces are wide, sometimes more than a mile, and continuous for several miles. Along many of the smaller streams they are continuous almost the entire length of the valley.

Some of the valleys in which these terraces were deposited were developed by consequent streams flowing across the unevenly distributed Mankato drift surface. Other valleys were formed before the

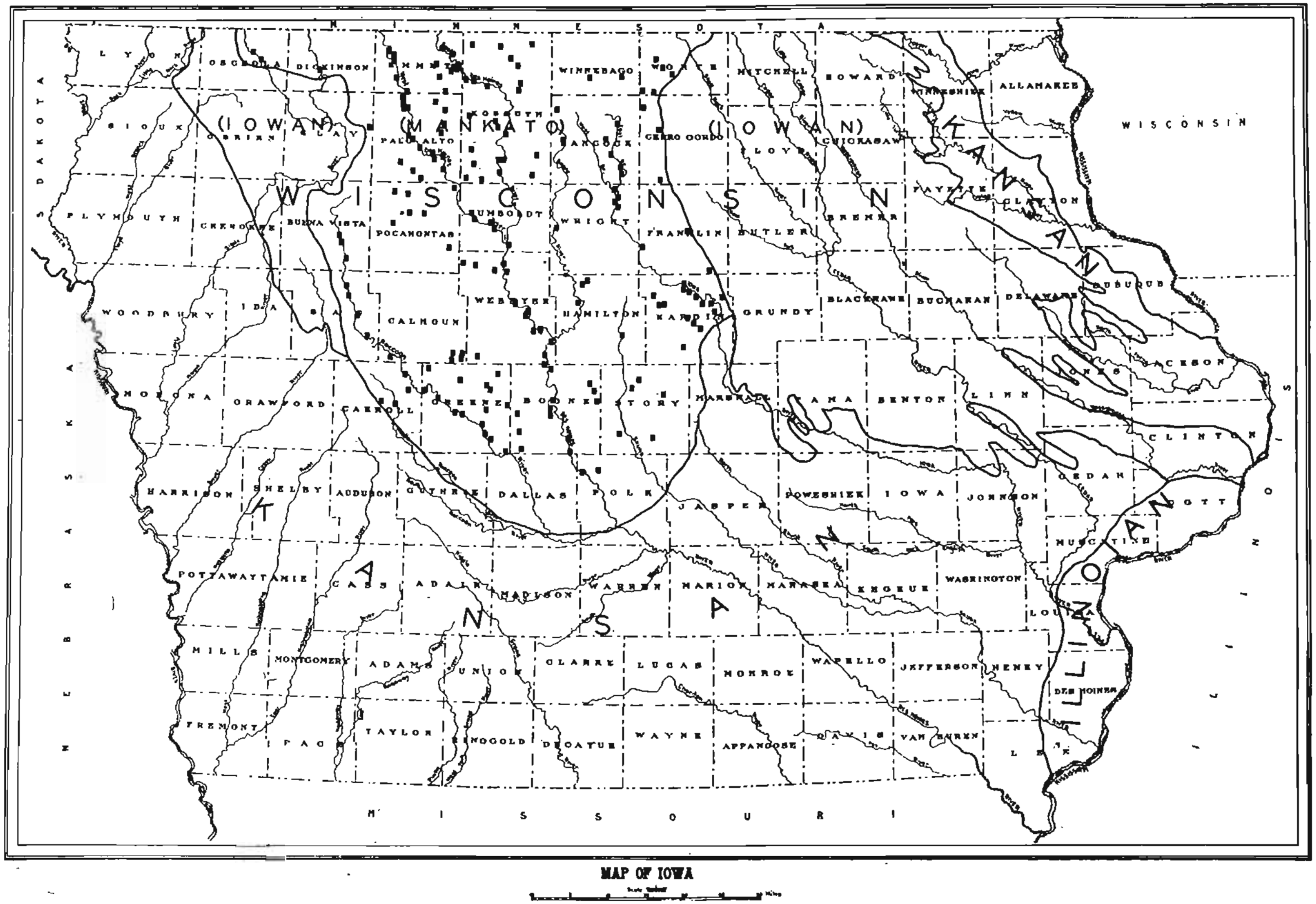


Fig. 52. — The squares show the locations of Mankato terrace gravel exposures within the Mankato drift area in Iowa.

advance of the Mankato glacier and were not entirely filled by the Mankato drift but afforded broad shallow valleys in which the streams from the melting Mankato ice flowed and deposited vast amounts of gravel. As shown by the lack of erosion on the surface of the Iowan drift outside the Mankato drift area, it seems doubtful that these valleys below the Mankato drift were formed during post-Iowan, pre-Mankato time; it is more probable that they were developed during post-Kansan gumbotil, pre-Iowan time and not entirely filled by the till deposition of the Iowan and Mankato ice sheets. This is further verified by the fact that these pre-Iowan drainage lines are more distinct within the Iowan area, where they are covered only by the thin Iowan drift and loess, than where they are also covered by the later Mankato drift.

Like the Iowan terrace deposits, the locations represented on the map are almost all gravel pits from which the gravel has been removed for road surfacing. Some, however, are artificial cuts and others are natural cuts along streams. As previously stated, these gravel terraces are practically continuous along the valleys, and the number of exposures is no definite criterion by which to determine their abundance but merely shows their presence and the fact that the gravel is more adaptable to commercial demand at that location.

The Characteristics of the Gravel

General Characteristics:

The Mankato gravel deposited along those streams which flowed from the melting Mankato glacier formed terraces which range in height from the level of the flood plain to more than 120 feet above the level of the stream. However, most of them are between 25 and 35 feet above the stream.

The overburden is unstratified silt, in some places sandy and in others loesslike, generally but not everywhere containing sparsely scattered pebbles which increase in number toward the base. It has a maximum observed thickness of 6 feet but may be a very thin layer or entirely absent. At the base it grades into the underlying gravel through a thin zone in which the interstices of the gravel are filled with the overburden, and generally the lower part of the overburden contains a few pebbles from the underlying gravel. This gradational zone is no doubt more pronounced in some exposures as the result of leaching which removed the carbonates from the upper part of the gravel, leaving spaces which the overburden might fill. Oxidation of the iron compounds colors the silt medium chocolate-brown (about 17'' ', Buffy-Brown) and by the addition of humus in the soil zone, the silt is colored to a darker brown (about 13'' ''i, Benzo-Brown). The carbonates are generally absent from the entire thickness of the overburden, although in some places only to a depth of about 30 inches. The apparent leaching to depths of 4 to 5 feet may be partly due to the topographic position, but it is more likely due to the small amount of carbonates in the original material. This is further substantiated by the fact that the depth of leaching extends just to the surface of the gravel in almost all of the exposures in which the overburden is more than about 30 inches thick, and into the gravel where it is thinner.

The gravel is highly calcareous except in a narrow leached zone at the surface of some exposures where the overburden is less than 30 inches thick, as described above. In addition to the primary carbonates, secondary lime forms concretions and cements some of the gravel in several of the exposures. The oxidation of the iron compounds colors some of the gravel rusty-brown (generally about 15'i, Ochraceous-Tawny) but it may be any shade from light grayish-buff to dark reddish-brown. Most of the gravel is gray to grayish-buff; however, that which is colored darker by iron oxide is in one of the following places: overburden, in thin layers parallel to the bedding, or perhaps within a lens of coarser gravel. Only a few of the igneous rocks such as granites, greenstones, and schists are weathered so that they crumble with application of slight pressure, but the gray shales fall to pieces soon after exposure to the atmosphere. The structure is fairly uniform throughout most of the exposures. The major stratification is in gently dipping beds ranging from less than an inch to several feet thick. Most of these beds are continuous but some extend only a few feet. Within the major horizontal beds cross-bedding is abundant and in places makes up the entire bed. Within the typical stratified material almost all of the gravel is smaller than 32 millimeters in diameter, as shown in the mechanical analyses of figure 53. However, included within this material are beds and lenses of coarser gravel in places containing cobbles as large as 20 centimeters in diameter mixed with smaller cobbles, pebbles, and only a small percentage of sand. Other coarse material is scattered through the finer material, and is unrelated to the stratification. Especially in northeastern Iowa

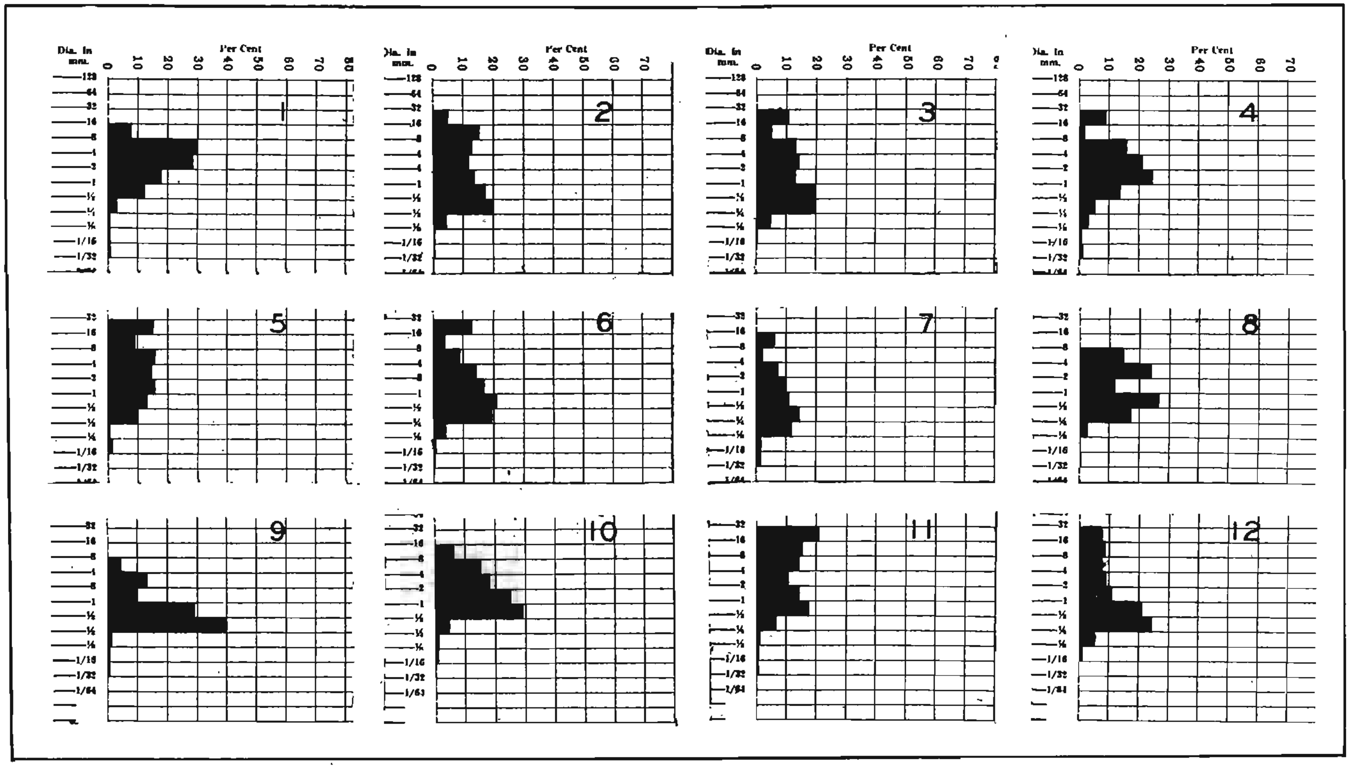


FIG. 53. — Graphs showing mechanical analyses of Mankato terrace and undifferentiated gravels. The numbers of these analyses correspond with those of figures 54 and 55.

the gravel contains a high percentage of limestone plates which comprise most of the coarse material. Generally they lie with their greatest diameters parallel to the bedding and thus make the stratification more distinct. The mechanical analyses of samples of average gravel from several exposures are shown graphically in figure 53. The percentage of rounding of each size grade between 1/16 and 32 milli-

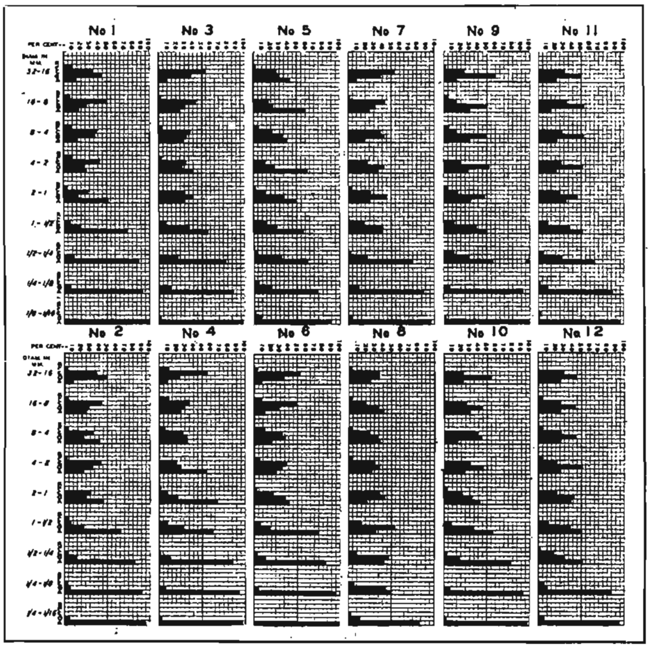


FIG. 54. — Graphs showing shape analyses of each size grade between 1/16 and 32 millimeters in diameter, of Mankato and undifferentiated gravels. The numbers of these analyses correspond with those of figures 53 and 55. R = rounded; r = sub-rounded; C = curvilinear; a = sub-angular; A = angular.

meters in diameter is shown in figure 54. Lithologic analyses of the pebbles between 16 and 32 millimeters in diameter are shown in figure 55.

In some exposures the gravel has been observed to overlie either till or loess. The loess appears to be Peorian and the till either Mankato or Kansan.

Characteristics of Exposures:

Mankato terrace gravel is exposed in a large gravel pit in the northeast quarter of section 19, Hardin township (T. 89 N., R. 20 W.),

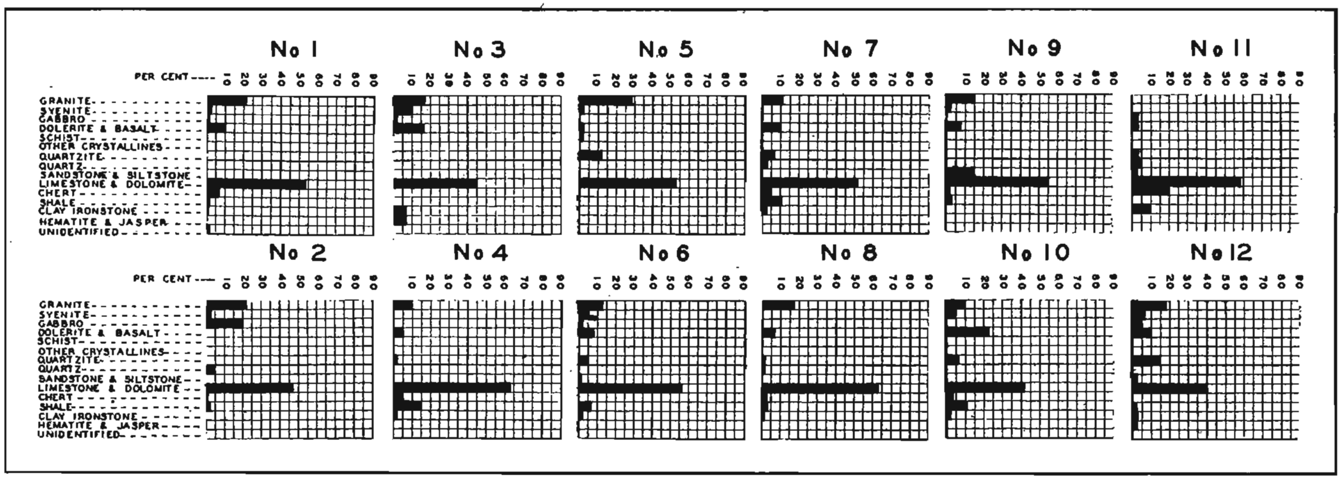


FIG. 55. — Graphs showing lithology of pebbles between 16 and 32 millimeters in diameter from the Mankato and undifferentiated terrace gravels. The numbers of these analyses correspond with those of figures 53 and 54.

Hardin county, along the south side of the Iowa river near the southeast corner of Iowa Falls. The gravel is in a terrace 50 to 55 feet above the river. The thickness of the gravel exposed ranges from 13 to 18 feet.

The light buffish gray gravel has almost no coloration by iron oxide. Most of the color is from the high percentage of grayish-buff limestone and dolomite. Leaching has removed the carbonates to a depth of 24 to 30 inches, primarily from the overburden; but where the overburden is thin, it may extend a few inches into the underlying gravel. No rocks observed in the section showed disintegration from weathering. The gravel in the west end of the pit is distinctly different from that in the remainder of the pit. Here, it resembles a river bar deposit and contains a high percentage of limestone and dolomite plates which make up more than 60 per cent of the deposit. Some of these plates attain an average maximum diameter of 30 centimeters. These coarse fragments are surrounded by a matrix of calcareous gravel which is practically all smaller than 2 centimeters in diameter. Although these plates are not stratified or interbedded with the finer material, as shown in figure 56, they tend to lie with their greatest

FIG. 56. — Mankato terrace gravel in an exposure near the southeast corner of Iowa Falls, along the Iowa river.

diameters parallel and also parallel to the poor stratification of the finer material; thus they give the entire mass a well-stratified appearance. The remainder of the pit, which constitutes abouts nine-tenths of the exposure, is much more uniform in both texture and structure than that just described. The clastic texture of the average gravel is more nearly like the matrix in which the limestone and dolomite plates are imbedded. It is well stratified in horizontal beds which overlap the southward dipping beds of the coarse material previously described. Within these average beds there are minor irregularities such as cross-bedding, and lens-and-pocket structures. About 85 per cent of the average gravel is between the size grades 1/2 and 8 millimeters in diameter. Some boulders are scattered through this finer material. There are also coarse pebbles, some approaching the size of cobbles, which occur in thin beds only one pebble thick along some of the bedding planes. The coarse material of the entire exposure consists almost entirely of platy fragments of limestone and dolomite. Likewise, most of the calcareous material is the same as that exposed in the quarries and limestone bluffs along the river in this same locality. A mechanical analysis of the average material is shown in No. 1 of figure 53. The percentage of rounding is shown in No. 1 of figure 54. The lithology is shown in No. 1 of figure 55. The overburden is fine unstratified silt which contains some pebbles scattered throughout the lower 1 foot. It is from 18 to 30 inches thick, leached of its carbonates, and colored medium-brown (17'' 'd, Vinaceous-Buff) by iron oxide and humus. In the east end of the pit the gravel overlies unleached and unoxidized till which thins out toward the west, where the oxidized but unleached loess below the till lies immediately below the gravel.

Less than 1/2 mile from the pit there are two quarries and three other exposures of gravel. Both the quarries, one on each side of the river, are at the same elevation as the terrace in which the gravel pit just described is located, 50 to 55 feet above the stream. One gravel pit along the north side of the river is also at this same level but the other is in a terrace about 25 feet lower. The third gravel pit is along the south side of the river in a terrace almost at the upland, 70 feet above the river. The characteristics of all these gravel exposures are quite similar.

Several exposures of Mankato terrace gravel in Polk county, near Polk City, show relations similar to those of the gravel pit described near Iowa Falls, in Hardin county.

The best of these exposures is near the center of section 1, Madison township (T. 80 N., R. 25 W.), in the east part of Polk City, on a terrace along the south side of Big Creek. Here the gravel has been removed to a depth of 26 feet from a terrace about 55 feet above the river.

The overburden is 2 feet thick. It is unstratified fine silt through which pebbles are scattered sparsely but in increasing numbers toward the base, where the overburden grades into the underlying gravel through a 4-inch transitional zone. The iron oxide colors the upper 6 inches of the gravel to the same color as the base of the overburden. Below this zone the gravel is practically uncolored by iron oxide, ranging from a very light-buff (15'i, Ochraceous-Tawny) in the coarser material to gray (17"b, Cinnamon-Buff) in the finer and almost white (21" 'f, Pale Olive-Buff) in the fine sand. Leaching has extended only about 6 inches into the gravel below the overburden. The upper 4 feet of gravel is poorly stratified and includes many lenses of both coarser and finer material as well as considerable cross-bedding. Pebbles as large as 5 centimeters in diameter are scattered through the poorly sorted coarse gravel. The 18 feet of gravel exposed below this is finer, well sorted, and stratified in beds seldom more than 8 inches thick, within which lenses, pockets, and alternating beds of sand are common. Practically nothing is larger than 2 centimeters in diameter. A mechanical analysis of an average sample from the lower 18 feet of gravel is shown in No. 2 of figure 53. The percentage of rounding is shown in No. 2 of figure 54. A lithologic analysis is shown in No. 2 of figure 55.

Another exposure of gravel is in an extensive terrace along the opposite side of Big Creek, in the southeast quarter of section 36, Madison township (T. 81 N., R. 25 W.). The gravel pit covers a wide area. Although no gravel has been removed for many years, it and related material can still be observed in a few places. In general the gravel and overburden are much the same as those along the opposite side of the stream, which have just been described. The gravel was deposited upon a very irregular surface, and except for one hole from which it has been removed to a depth of about 25 feet, the gravel was less than 15 feet thick. Unleached and unoxidized till is exposed in several places in the base of this pit.

Another exposure of gravel showing relations to associated deposits similar to those just described is in a terrace about 55 feet above the level of the Des Moines river. It is in the northeast quarter of section 30, Jefferson township (T. 81 N., R. 25 W.), Polk county. Here 15 feet of gravel is exposed below the usual silty overburden. The gravel differs from other exposures just described, near Polk City, in that it is coarser and poorly stratified. The upper 3 feet is coarser than that below, containing much material as large as 8 to 10 centimeters in diameter. At the base of the gravel, there is a single layer of cobbles, each cobble having an average diameter of about 15 centimeters. Underlying the gravel several feet of fresh till is exposed in the ditches along the road.

At Belmond, Iowa, at the confluence of the West Branch of the Iowa river with the East Branch of the Iowa river, there is an extensive terrace in which the gravel is exposed in four large pits and several small pits. The gravel here has been removed from several acres, but at present the workings are abandoned and most of the worked faces are concealed by vegetation and slumped material. All of the pits are in a terrace about 25 feet above the streams.

The best one of these exposures in which to study the gravel is in the south part of town, in the southwest quarter of section 30, Pleasant township (T. 93 N., R. 23 W.), Wright county, along the east side of the Iowa river.

The overburden is of the usual type, unstratified silt 18 to 40 inches thick. It contains pebbles scattered throughout the mass, but becoming more numerous at the base, where the silt grades into the underlying gravel. Leaching has removed the carbonates from all of the overburden. Where it is only 18 inches thick, leaching has extended to a depth of 10 inches into the underlying gravel, but where it is 4 feet thick, the gravel is calcareous to the base of the overburden. Where the gravel is leached below the overburden there is a more distinct gradation between the two than where it is unleached. Oxidation and humus color the upper part of the overburden dark chocolate-brown (13" "i, Benzo-Brown). Below the humus zone the overburden is lighter-brown (17" ', Wood-Brown). In the transitional zone between the gravel and overburden, the gravel is colored rusty brown (17"i, Tawny-Olive) about the same as the overburden, but lower down the gravel is only slightly colored by iron oxide. Only a few of the rocks show signs of disintegration by weathering, except the gray shale which falls to pieces readily when exposed to the atmosphere. The gravel is well stratified in horizontal beds within which cross-bedding and lens-and-pocket structures are common. The gravel is well sorted and even textured throughout the exposure. About 80 per cent is between 1/4 and 8 millimeters in diameter, and practically nothing observed was larger than 8 centimeters in diameter except one boulder in the bottom of the pit which was 30 centimeters in diameter. A mechanical analysis of a sample of average material is shown in No. 3 of figure 53. The percentage of rounding of each size grade between 1/16 and 32 millimeters in diameter is shown in No. 3 of figure 54. The lithology determined from an analysis of pebbles is shown in No. 3 of figure 55. The gravel in the pit is 17 feet thick but no underlying material is exposed.

The other exposures in this terrace near Belmond show the same relations to the overburden and terrace as the one just described but vary in some other aspects such as lithology and textural range.

Many exposures of gravel are in a terrace about 1/2 mile square and standing about 30 feet above the East Branch of the Des Moines river, in the east part of section 26, Armstrong Grove township (T. 99 N., R. 31 W.), Emmet county. The gravel is practically the same in all of the exposures studied.

The characteristics of the material exposed in these pits are quite similar to those of the other terrace deposits described. The 15 feet of gravel overlies unoxidized and unleached till which was observed in the bottom of one pit. Analyses of texture, shape and lithology are shown in No. 4 of figures 53, 54, and 55.

Mankato terrace gravel is exposed in many places in the broad terraces along the West Fork of the Des Moines river, especially in Emmet and Palo Alto counties, but the terraces are continuous from north of the Minnesota line south into Humboldt county.

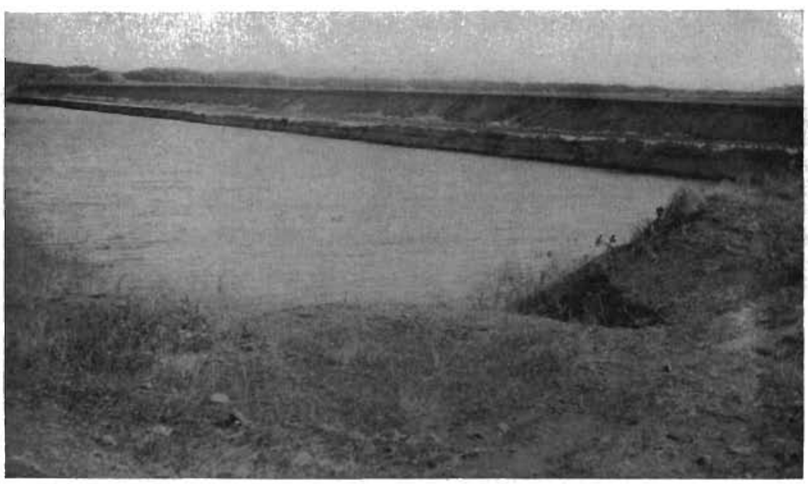


FIG. 57. — Large exposure of Mankato terrace gravel along the Des Moines river north of Graettinger, Emmet county.

A large exposure of gravel is in a pit north of Graettinger, operated by the Chicago, Rock Island Railway Company. It is a narrow elongated pit, as shown in figure 57, which extends from the south central part of section 29 to the center of section 32, High Lake township (T. 98 N., R. 33 W.), Emmet county. Here the gravel is reported to have been removed to a maximum depth of 45 feet. However, 20 feet is the greatest thickness exposed above the water in the pit.

The overburden of the usual silty material is about 4 feet thick. It contains pebbles scattered throughout the entire thickness but becoming more numerous toward the surface of the underlying gravel. There is only a slight gradational zone between the overburden and the gravel. Leaching has removed the carbonates to a depth of 24 inches, below which there is an occasional limestone pebble in the overburden and the average gravel is about 50 per cent carbonates. Except for a few lenses and thin beds which are colored rusty-brown (15'i, Ochraceous-Tawny) by iron oxide, the gravel is light buff-gray (17"ib, Avellaneous). It is well stratified in beds averaging about 2 feet thick which dip slightly toward the southwest. Within beds of finer material there is a small amount of cross-bedding and lens-and-pocket structures. Most of the gravel is smaller than 3 centimeters in diameter and only one boulder was seen. It is possible, however, that there were other boulders and cobbles which have either been hauled away or thrown back into the pit. A mechanical analysis of the average material is shown in No. 5 of figure 53. The percentage of rounding is shown in No. 5 of figure 54. The lithology is shown in No. 5 of figure 55.

Gravel is exposed in many other places in the terrace along this part of the Des Moines river. Around Graettinger there are several exposures along the west side of the stream in this terrace. Similar exposures are found in the west side of Emmetsburg, in one of which the gravel has been reported to have been removed to a depth of more than 40 feet. At Wallingford the gravel has been removed from a considerable area. Here the underlying till is reached in several places at various depths, generally less than 30 feet. Other large pits in and near Estherville have been described by previous writers.[56] Lees[57]

[56] Macbride, T. H., Geology of Emmet, Palo Alto, and Pocahontas counties: Iowa Geol. Survey, Vol. XV, pp. 245-250, 1905.
Beyer, S. W., The Road and Concrete Materials of Iowa: Iowa Geol. Survey, Vol. XXIV, pp. 507-508, 1914.

[57] Lees, James H., Physical Features and Geologic History of Des Moines Valley: Iowa Geol. Survey, Vol. XXV, pp. 423-615.

has described the Des Moines river valley in all of its aspects from its source in Minnesota to its mouth at the southeast corner of Iowa.

One of the many exposures of gravel along the Raccoon river is near the center of section 13, Jackson township (T. 83 N., R. 31 W.), Greene county, about 1/2 mile from the southwest corner of Jefferson. Here 13 feet of gravel is exposed in a terrace 20 feet above the level of the river.

The surface of the gravel is irregular, which makes the layer of overburden range from 2 to 4 feet in thickness. Leaching has removed the carbonates to a depth of about 40 inches in the overburden, below which there are limestone pebbles, but where the overburden is only 2 feet thick the carbonates are removed from the upper few inches of the gravel. Oxidation and humus color the upper 16 inches of the overburden to a dark chocolate-brown (13" "i, Benzo-Brown), below which the oxidation alone colors the remaining overburden and the underlying transition zone between it and the gravel to a lighter brown (17" ', Buffy-Brown). A layer of coarse gravel 1 to 4 feet thick immediately below the overburden is colored by iron oxide to a light rusty-brown (15'i, Ochraceous-Tawny). It is poorly stratified except in certain beds and lenses of finer gravel and sand. Almost all of this gravel is finer than 3 centimeters in diameter and nothing larger than 10 centimeters in diameter was observed. The remaining 9 to 12 feet of gravel is finer, almost all smaller than 8 centimeters in diameter. It is colored light grayish-buff (19"i, Isabella Color) by the light-gray rocks and slight oxidation of the iron compounds. The beds are about 30 inches thick and dip at a low angle toward the north. Cross-bedding is abundant in some of the beds. It dips at an angle of about 40 degrees in any direction but mostly toward the southeast. A mechanical analysis of a sample of average material from this lower part of the section is shown in No. 6 of figure 53. The percentage of rounding is shown in No. 6 of figure 54. The lithology of the pebbles is shown in No. 6 of figure 55. An analysis of cobbles between 6 and 15 centimeters in diameter from the base of the pit shows the following kinds and shapes of rocks:

		Number of cobbles of each shape				
	Per Cent	A	a	C	r	R
Limestone and dolomite	71.3	60	77	50	100	
Granite	19.1	40	15			
Dolerite and basalt	9.6		8	50		

The gray shale in the gravel weathers so readily on exposure that it does not appear in its correct proportion in a lithologic analysis. Besides the shale, some of the granites and schists are weathered in the upper layer of coarse gravel. Unleached and unoxidized till is exposed in the base of the pit.

Relations of the Gravel

The Mankato terrace gravel was deposited in valleys in front of the melting Mankato glacier. Some of the valleys were developed by consequent streams on the surface of the freshly deposited Mankato drift, others were pre-Wisconsin valleys only partly filled by the Mankato till, and still others were a combination of both.

The relationship between the Mankato terrace gravel and other materials is determined primarily by the erosional and depositional history of the valleys.

The erosion which began dissecting the Kansan gumbotil plain during late Yarmouth time continued until the advance of the Iowan ice in practically all of the state except that covered by the Illinoian glacier. During this interval, the Loveland, deep valleys were developed in which gravel was deposited. In northwestern Iowa, where so much erosion took place, deposits of Loveland gravel can be differentiated in those valleys which do not contain Iowan or Mankato gravel.

The thin Iowan drift did not fill these valleys but only spread over the surface as a blanket. Thus during both the advance and retreat of that ice sheet these valleys carried the water and received the outwash gravel from the melting ice. When the Mankato glacier advanced over this area these unfilled valleys again received the drainage and outwash gravel from the melting ice.

In northwestern Iowa where gravels of these three ages have been deposited in the same valleys it is impossible to differentiate one from the other on the basis of characteristics. However, in northeastern Iowa the Loveland gravel has not been recognized but the characteristics of the Iowan and Mankato are quite similar. Since it is possible for three ages of gravel to occupy some of the valleys the basis for determining their age depends upon their relationship to the surrounding till and loess deposits.

In Hardin county, in the southeast quarter of section 19, Hardin township (T. 89 N., R. 20 W.), along the south side of the Iowa river, near the southeast corner of Iowa Falls, Wisconsin terrace gravel is exposed about 25 feet below the upland and 50 to 55 feet above the river. Along this same side of the river and a few hundred yards farther east similar gravel is exposed in a terrace 20 feet higher. Across the river to the north is another exposure in a terrace at the same elevation as the first, 50 to 55 feet, and another about 25 feet lower; all of the exposures have similar characteristics. No evidence would lead toward the conclusion that any of these terraces were other than of Mankato age.

In the first exposure mentioned, along the south side of the stream, the gravel is covered by the usual type of unstratified silty overburden. The gravel overlies both unleached and unoxidized till and unleached and oxidized loess. The fresh, dark-colored till is exposed in the east part of the pit but becomes thinner toward the west, where it is replaced by the loess. Two possible interpretations could be placed on the till and loess below the gravel. They could be Iowan till from which the weathered zone had been eroded away, overlying unleached Loveland loess, or Mankato till overlying Peorian loess. No evidence conflicts with the latter interpretation, but the former is difficult to support.

Another exposure of Mankato terrace gravel overlying unleached and unoxidized till is along the south side of the Des Moines river, in the northeast quarter of section 30, Jefferson township (T. 81 N., R. 25 W.), Polk county. Here 15 feet of gravel is exposed in a terrace 55 feet above the stream. It is covered by the usual unstratified silty overburden and overlies fresh till which can be definitely correlated with the Mankato till which forms the upland.

About 5 miles southeast of here, in the southeast quarter of section 36, Madison township (T. 81 N., R. 25 W.), Polk county, is another exposure of Mankato terrace gravel which overlies unaltered Mankato till.

Still another exposure in which the gravel can be observed overlying unaltered Mankato till is along the Raccoon river near the center of section 13, Jackson township (T. 83 N., R. 31 W.), Greene county, about 1/2 mile southwest of Jefferson. Here about 13 feet of gravel occurs in a terrace 20 feet above the level of the river.

In the gravel pits and prospect holes made by the Iowa State Highway Commission along the Des Moines river just east of Wallingford the fresh Mankato till has been observed below the gravel in many places and the exact relations of the two have been studied.

Within the Iowan drift area beyond the Mankato drift, in the central part of the north side of section 33, Eldora township (T. 87 N., R. 19 W.), Hardin county, just across the Iowa river east of Secor, the Mankato gravel is exposed in a terrace about 45 feet above the stream. Here the 10 feet of gravel lies below 4 to 5 feet of oxidized and leached loesslike silt. The gravel lies upon oxidized but in most places unleached loess. The relations are comparable to those described near Iowa Falls except that this is beyond the Mankato drift area and consequently no unaltered till occurs between the loess and gravel. There can be no doubt but that the loess is of Peorian age and the gravel outwash from the Mankato glacier.

Several other exposures of Mankato terrace gravel show relations similar to those just described. However, in most of the exposures the relations with the associated material other than the overburden are not visible. The overburden covering the Mankato terrace gravel is of practically no value in correlation, because it is a deposit which might be found above gravel of any age or type.

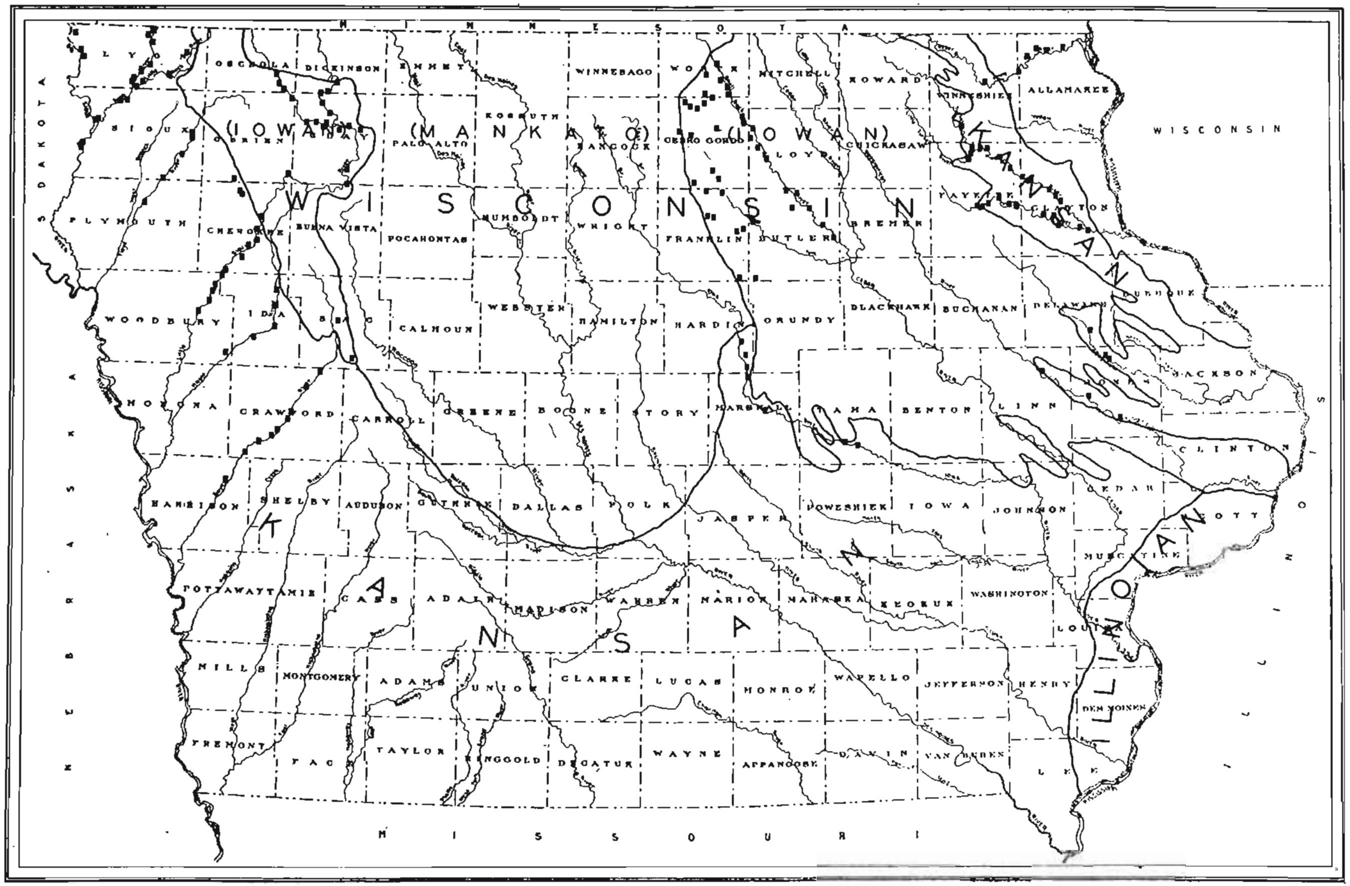
The Age of the Gravel

The relations of the deposits of Mankato terrace gravel within the Mankato drift area have been observed in several places. In these exposures the gravel overlies unaltered Mankato till so must have been deposited during the retreat of the glacier. Some gravel, no doubt, was deposited during the advance of the ice, but no such exposures were observed.

The Undifferentiated Terrace Gravel of Iowa

The Distribution of the Gravel

Terrace gravel is found in almost every valley in the northern part of Iowa and in many of those of southern Iowa. They represent three different periods of deposition — Loveland, Iowan, and Mankato. In some of the valleys the gravel of these different ages can be differentiated but in other valleys this has not been possible. In as much as it has not been possible to separate the gravel of the different ages; they will be described as undifferentiated gravel. The locations of these deposits are shown in figure 58.



MAP OF IOWA

FIG. 58. — The squares show the locations of exposures of undifferentiated terrace gravel.

The Characteristics of the Gravel

General Characteristics:

There are no distinct characteristics by which this gravel can be differentiated from the Loveland, Iowan, or Mankato.

The exposures along most of the streams which head up within the Iowan area have characteristics comparable to those of Iowan terrace gravel. However, even though Loveland gravel were present it would be very similar to the Iowan, because in those valleys where the age is known, the two cannot be differentiated on the basis of the characteristics of the material.

Those valleys whose heads are within the Mankato drift area more commonly have characteristics like the Mankato terrace gravel of the Mankato drift area. However, along Otter Creek and Little Rock River, both of which head up within the Mankato drift area, some of the exposures are definitely Iowan in age.

Although these generalizations can be made, the characteristics of the Loveland, Iowan, and Mankato terrace gravel deposits are so much alike that one would in most cases hesitate to attempt to separate one from the other if their relations to other materials were not known.

Characteristics of Exposures

A large exposure of this type of gravel is within the Iowan drift area just beyond the margin of the Mankato drift, in the southwest quarter of section 8, Lake township (T. 96 N., R. 21 W.), Cerro Gordo county, along the valley of Willow Creek, 1 mile east of Clear Lake. Here the gravel is exposed in a terrace which stands 25 feet above Willow Creek and has a width of about 1 mile. The gravel has been removed to a depth of 40 feet, the lower 25 feet from below the water standing in the pit.

The overburden is unstratified sandy silt from 2 1/2 to 4 feet thick and contains small pebbles in the lower part. Leaching has removed the carbonates from its entire thickness but the underlying gravel and the narrow transition zone separating the two are highly calcareous. Oxidation of iron compounds colors the overburden and the transition zone to medium chocolate-brown (17"I, Wood-Brown) but the addition of humus colors the upper part of the overburden darker brown (13" "i, Benzo-Brown). The gravel below the transition zone is gray-buff (17" 'b, Avellaneous) except for a few thin beds and lenses which are colored rusty-brown (15'i, Ochraceous-Tawny) by iron oxide. Weathering has disintegrated a few of the coarse crystalline rocks, and the large amount of shale falls to pieces soon after exposure to the atmosphere. The gravel exposed above the water is only fairly well sorted but well stratified in almost horizontal beds from 6 to 20 inches thick, within which is much cross-bedding and lens-and-pocket structure. The material is primarily sand and fine gravel (see figure 59). None of the stratified material is larger than

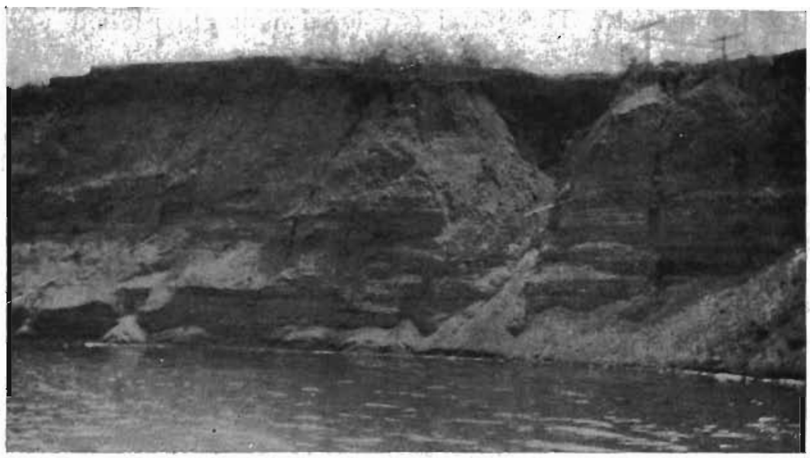


FIG. 59. — Undifferentiated terrace gravel exposed along Willow Creek near the margin of the Mankato drift, Cerro Gordo county.

10 centimeters in diameter and more than 90 per cent of it is below 3 centimeters in diameter. In this large pit only three boulders were observed but no doubt several had been dumped back into the pit and are now covered by water and rejected fine material. The percentage of each size grade, determined by a mechanical analysis, is shown in No. 7 of figure 53. The percentage of rounding of each size grade is shown in No. 7 of figure 54. A pebble count shows the percentage of the different kinds of rock as given in No. 7 of figure 55.

There is another large pit in Cerro Gordo county in the northeast part of Mason City, Mason township (T. 96 N., R. 20 W.), along the west side of Lime Creek. Here the terrace gravel is exposed in an extensive terrace which stands about 28 feet above the river. The gravel has been removed from an area which covers about 1/2 square mile, and to a depth of about 25 feet, which is partly below the water standing in the base of the pit.

The overburden is unstratified silt with an average thickness of about 2 feet, containing pebbles smaller than 3 centimeters in diameter scattered throughout its entire thickness but in increasing numbers toward the base. It is separated from the underlying gravel by a transition zone only a few inches thick. Leaching has removed the carbonates from all of the overburden and the upper 3 to 9 inches of the gravel. Oxidation and humus color the upper 12 to 16 inches of the overburden dark chocolate-brown (13'' ''i, Benzo-Brown) while that below and the transitional zone are colored (17'' ', Wood-Brown) by oxidation alone. The gravel is colored light grayish-buff (19''i, Isabella Color) by iron oxide. Weathering has disintegrated some of the igneous rocks and the gray shale falls to pieces soon after exposure to the atmosphere. Aside from some of the coarsest gravel which forms a poorly stratified mass, the gravel is all stratified in horizontal beds within which there is cross-bedding and lens-and-pocket structures. Most of the material is coarse sand and fine gravel with only a narrow size range. Other than one boulder, nothing larger than 13 centimeters in diameter was observed and only a small percentage is larger than 3 centimeters in diameter. Of this coarse material, about 85 per cent is limestone plates of which about 65 per cent is sub-angular, and the remainder is about equally divided between the angular and curvilinear shapes. A mechanical analysis of average material is shown in No. 8 of figure 53. The percentage of rounding is shown in No. 8 of figure 54. The rock content of pebbles is shown in No. 8 of figure 55. Water stands in the base of this pit; thus no underlying material is exposed.

This same type of gravel has been removed from this terrace at many locations in the east side of Mason City and from along the valley of Lime Creek both to the north and south. The exposure just described is near the union of Lime Creek and Willow Creek, both of which carried vast amounts of sand and gravel from the melting Mankato glacier. This deposit is not more than 17 miles from the Mankato drift margin by either river course.

In Butler county, in the southeast quarter of the northwest quarter of section 35, Butler township (T. 92 N., R. 15 W.), 1 mile north of Shellrock, gravel is exposed in a terrace which stands 25 feet above the stream. The gravel has been removed to a depth of 60 feet but what occurs below that depth is not known; it is probably bedrock.

The overburden is a 2-foot bed of unstratified silt with small pebbles scattered sparsely throughout its thickness. The upper 2 feet of gravel is colored by iron oxide to almost the same light-brown color as the lower part of the overburden but below this it is distinctly fresh; the color is only slightly darker gray than the limestone which makes up a high percentage of the material. The gravel is leached of its carbonates in only the upper few inches. It is well stratified in horizontal beds generally between 6 and 18 inches thick within which there are cross-bedding, lens, and pocket structures. The material is chiefly coarse sand and fine gravel, and extremes in either coarser or finer material are rare. An analysis of the material as it comes from the pit shows the following: sand, 82 per cent; gravel, 1 to 2 centimeters in diameter, 7 per cent; gravel, 2 to 5 centimeters in diameter, 11 per cent; and a small amount larger than 5 centimeters in diameter. The percentage of each size grade, determined by a mechanical analysis of a sample of average gravel, is shown in No. 9 of figure 53. The percentage of rounding is shown in No. 9 of figure 55.

Along this part of the stream some of the terrace gravel differs from that described. Some consist almost entirely of sand within which the coarse material is almost all platy limestone, while others contain a high percentage of pebbles between 1 and 5 centimeters in diameter interstratified with the sand and fine gravel as well as being scattered throughout the finer gravel. One of these pits from which the gravel has been removed over a wide area is in the northwest quarter of section 1, Jackson township (T. 92 N., R. 16 W.), Butler county, about 2 miles north of Clarksville. Here a high percentage of the gravel is larger than 3 centimeters in diameter and is almost all limestone much of which is platy. The terrace stands 26 feet above the Shellrock river.

Undifferentiated terrace gravel deposits similar to those described in northeastern Iowa are exposed in many places in northwestern Iowa along those streams which carried the water from the melting Mankato ice. Along Rock River there are many exposures; some of the best and most abundant are near Doon. Here the town is built on a wide gravel terrace which is about 28 feet above the stream. Gravel is exposed in several pits in and near Doon; the best exposure is in the northwest part of town. This is in the northeast quarter of section 26, Doon township (T. 98 N., R. 46 W.), Lyon county.

The overburden is about 3 feet thick. It consists of unstratified silt which contains some small pebbles scattered throughout the lower

1 foot. It grades into the underlying gravel through a narrow transition zone. Oxidation of the iron compounds colors the overburden to the usual shade of brown. The gravel is gray (17"b, Cinnamon-Buff) except for one bed about 6 inches thick at a depth of 11 feet, which is partly colored black by manganese dioxide and the remainder colored rusty-brown (15'i, Ochraceous-Tawny) by iron oxide. These oxides coat the grains and in some places form a weak cement. Leaching has removed the carbonates from all of the overburden but the underlying gravel is highly calcareous. Some of the crystalline rocks such as schists and granites are weathered so that they crumble along their margins. Prospects show the gravel to extend 16 feet below the bottom of the pit, making its total thickness 35 feet. The gravel overlies unleached and unoxidized till. All of the stratification and cross-bedding dip in a general southerly direction. A mechanical analysis of the average gravel of this section is shown in No. 10 of figure 53. The percentage of rounding is shown in No. 10 of figure 54. The lithology is shown in No. 10 of figure 55.

Another exposure along the Rock river is only a few miles from its confluence with the Big Sioux river. It is near the center of section 17, Garfield township (T. 96 N., R. 47 W.), Sioux county, about 1 mile east of Hudson, South Dakota. Here the gravel is exposed in a gravel pit in the terrace which stands 35 feet above the level of the

FIG. 60. — Undifferentiated terrace gravel exposed in a gravel pit about 1 mile east of Hudson, South Dakota. The terrace which stands about 35 feet above Rock River can be seen in the background.

stream (see figure 60). As shown in Plate I of Carman's report,[58] the gravel terrace here is as much as 4 miles wide covering all of the divide between the Rock and the Big Sioux river. The grader ditches along the roadsides have exposed this gravel below the thin overburden in many places. The gravel is exposed in a pit to a depth of 18 feet.

The overburden ranges from a few inches to 2 feet in thickness. It is fine unstratified silt, leached of its carbonates and colored dark chocolate-brown (13'' ''i, Benzo-Brown) by humus and oxidation of the iron compounds. Only a narrow gradational zone separates the gravel from the overburden. The gravel ranges in color from buffish-gray (19''i, Isabella Color) to dark brownish-red (11'm, Chestnut-Brown), and some is colored black by manganese dioxide. Secondary lime cements the gravel into a weakly coherent conglomerate in the upper 4 feet. Most of the gravel is well sorted and stratified. A few almost horizontal beds of coarse gravel are continuous throughout the pit but cross-bedding, lenses, and pockets are common. The gravel beds all dip toward the southeast and some cross-bedding dips as much as 50 degrees. An average of the material is represented in the mechanical analysis of No. 11 of figure 53. The shape of each size is shown in No. 11 of figure 54. The lithology of pebbles is given in No. 11 of figure 55. At the base of the 18 feet of gravel is a 2-foot layer of blue-gray, unleached and unoxidized, fossiliferous silt, which is continuous throughout the bottom of the pit. It includes thin stringers of gravel and a few scattered pebbles. This is underlain by highly calcareous gravel similar to that above the silt.

The Little Sioux valley north of Spencer, in Clay county, is bordered by what appear to be Mankato outwash terraces throughout most of its course. These have been described by Carman[59] as follows:

"This gravel area extends as a terrace down the Little Sioux valley to the county line and south to Spencer. At Milford the terrace is 70 to 80 feet above the river, but it declines to 50 feet at the county line, and to 20 feet at Spencer, as shown in figure 19. In this distance the river falls 70 feet while the terrace drops about 120 feet. The fall of the terrace measured along the center line of the filled belt is 6⅔ feet per mile, and the fall of the river along this same line is about four feet per mile. The fall

58 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, 1931.
59 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, p. 150, 1929.

of the river from west of Milford to Spencer, measured along its winding course, is 2⅔ feet per mile."

One of the exposures along this terrace is in the southwest quarter of section 21, Lakeville township (T. 99 N., R. 37 W.), Dickinson county, about 5 miles northwest of Milford. The gravel here is exposed to a depth of 15 feet in the outwash terrace which stands 70 feet above the river.

The overburden is unstratified loesslike silt; it contains a few scattered pebbles, and grades into the underlying gravel through a narrow transitional zone. It is less than 2 feet thick, leached of its carbonates, and colored to the usual color by iron oxide and humus. None of the gravel is leached below the transitional zone and near the base of the pit some of it is cemented by secondary lime. Iron oxide which occurs in thin belts which are seldom more than 1/2 inch thick, colors much of the gravel rusty-brown (15'i, Ochraceous-Tawny) within the upper 8 feet of the exposure. Some of the igneous rocks are weathered so that they crumble along their margins, and the gray shale falls to pieces soon after exposure to the atmosphere. A mechanical analysis of average material is shown in No. 12 of figure 53. The percentage of rounding is shown in No. 12 of figure 54. An analysis of pebbles is shown in No. 12 of figure 55.

Other exposures similar to this occur along the terrace between here and Spencer. The greatest difference is that they show more uniform structures farther from the Mankato drift margin.

In Lyon county, in the west central part of section 33, Dale township (T. 98 N., R. 43 W.), there is a group of exposures of gravel in a terrace about 25 feet above the level of the stream.

The coloration of the gravel by oxidation varies from gray (17'' 'b, Cinnamon-Buff) to medium-buff (15'i, Ochraceous-Tawny). The differences in color are generally within the lenses, pockets, or thin beds of material which are either finer or coarser than the surrounding material. None of the gravel is leached below the 7 feet of overburden and the only disintegration by weathering is within a few coarse crystalline boulders. The upper 4 feet of the 10 feet of gravel exposed is finer than the gravel of the lower 6 feet, but both show practically the same structure. The gravel is well stratified in horizontal beds about 14 inches thick, within which cross-bedding is common, dipping toward the southwest in places at an angle of as much as 45 degrees.

In these exposures there is very little coarse material; only two boulders were observed and both were smaller than 30 centimeters in diameter. Practically all of the gravel is smaller than 4 centimeters in diameter. The gravel is overlain by about 7 feet of typical Peorian loess, and the two are separated by a sharp but irregular surface. The loess is colored to light chocolate-brown in the upper soil zone by iron oxide and humus, below which it is the usual buff color (17" 'd, Vinaceous-Buff) of loess. Leaching has removed the carbonates to a depth of 4 1/2 feet, below which there are many lime concretions.

In northeastern Iowa there are many exposures of gravel beyond the Iowan drift area which are covered by Peorian loess as the exposure just described in northwestern Iowa. They probably represent Iowan deposits but they could be either Loveland, Iowan, or both.

The Relations of the Gravel

The undifferentiated terrace deposits include gravel of three distinct ages. They are the Loveland interglacial gravel, the Iowan glacial outwash gravel, and the Mankato glacial outwash gravel. The relations of each of these to associated materials have been discussed in this report for the areas in which only that gravel occupies the valleys. However, along certain valleys where gravel of more than one age was probably deposited, it is impossible to differentiate the gravel of one age from that of another.

The Loveland gravel was deposited in the valleys cut in the Kansan drift and older deposits during the Loveland interval. Thus their age is post-Kansan gumbotil erosion and pre-Wisconsin.

The Iowan ice advanced over part of this eroded Kansan drift surface which has Loveland gravel deposited along its valleys. The thin Iowan drift did not fill these valleys and level the surface but spread over the irregularly eroded surface like a blanket. The water from the melting ice carried gravel that was deposited along these valleys. In the region covered by Iowan drift which partially filled the valleys, the Iowan terrace gravel was deposited above the Iowan drift. Within the Kansan drift area, beyond the Iowan margin, the Iowan terrace gravel must have been deposited above the Loveland gravel. However, the large volume of water from the melting Iowan ice probably removed and reworked much of the Loveland. In either case gravel of both ages would be included in the deposits. Even if the Iowan had not reworked the Loveland, the two were so close to the same age that one would not expect to observe a weathered zone between them. Peorian loess was spread widely over this state after Iowan time and before Mankato time.

Some of these valleys extend from the Kansan drift area, across the Iowan and into the Mankato, but where the Iowan is missing the valleys extend from the Kansan area directly into the Mankato. The valleys whose heads are within the region covered by the Mankato glacier received outwash gravel as the ice melted. Where the streams flowed from the Mankato drift area across the Iowan drift area and out into the Kansan drift area, they either deposited Mankato outwash gravel over the older deposits within the valley or reworked and redeposited them all as a single unit. Where the streams flowed directly from the Wisconsin drift region into the Kansan, no Iowan gravel could be included.

No contact between gravel of different ages was observed in any exposure. This would suggest that the older deposits were reworked and redeposited by the water transporting the younger gravel. However, the terraces are not commonly more than 35 feet above the stream and the contacts with older gravel might be below the level of the ground-water surface. However, it seems probable that they were reworked and incorporated into a single deposit during deposition of the younger gravels, since in some exposures within the Iowan area where the gravel has been removed or prospected to the bedrock surface there is no indication of more than one deposit.

THE ORIGIN OF THE PLEISTOCENE GRAVEL

As the glaciers moved outward from their centers of dispersion they removed vast amounts of detrital material from the surfaces over which they passed and transported it to where it was later deposited as drift as the ice melted. The drift includes heterogeneous material — till — let down in situ from its transported position within the glacier as the ice melted, and stratified sand and gravel transported and deposited by streams flowing from the melting ice. As the ice melted any concentrations of water, forming streams, were able to acquire a ready load either from the glacier itself or from the freshly deposited drift surface in front of the melting ice margin. These streams must have transported a maximum load at all times, and any change in conditions along their course caused a change of load which resulted in deposition from place to place. Sand and gravel deposited on the older drift surface and later overridden by the advancing glacier were in many cases picked up and reincorporated in the younger glacier's load. The sand and gravel deposited beyond the active ice margin, as the ice front was stationary or retreating, remained undisturbed where it was deposited.

The following distinct types of gravel deposits have been observed: (1) irregular masses — "gravel boulders" — seldom more than 15 feet in average diameter were observed at several locations in Iowa. In most places they are in the lower part of the till sheet (see figure 61). In these gravel boulders the bedding planes are inclined at angles sometimes greater than the angle of repose, and could not represent original deposition in place. In some of these masses the lithology is similar to that of the surrounding till but in others it is distinctly different. While some are unleached masses within unaltered till, others are leached masses within unaltered till. All of the characteristics indicate that these are fragments of larger deposits of gravel which, while in a frozen condition, were broken up by the advancing glacier; and the fragments were incorporated as boulders in the till. (2) Irregular masses of gravel sometimes more than 100 feet in horizontal diameter and more than 40 feet thick are inclosed within the till. They are generally within a few feet of the upper till surface but may be

Fig. 61. — Sand and gravel boulders in the Kansan drift in Lucas county.

at any depth (see figure 51). Although in a few exposures the bedding planes are tilted, they are generally approximately horizontal like those of original deposition. In some exposures there is a distinct break between the gravel and surrounding till while in others the two are separated by a gravelly till transitional zone. The lithology is similar to that of the till and both clay-balls and masses of till are often present. If these gravel masses are within the altered zone of the including till, their alteration is comparable to that within the till. However, if they are within unaltered till they also are unaltered except for oxidation. In none of those exposures observed were the upper beds plowed up by an overriding ice sheet which deposited the overlying till. (3) At several locations lenses and thin beds of sand and gravel are buried within the till. Like the masses described under No. 2, these appear to represent deposition in place and show no signs of distortion of the beds by a readvance of the ice. In places there are as many as ten of these layers or lenses of sand and gravel separated by thin layers of till. Along the margins, some of these lenses feather out in a delicate manner. Their alteration is in harmony with that of the surrounding till. (4) One of the most common types of gravel is irregular masses included within but at the upper surface of the including till sheet. The gravel of these masses is generally in the position of original deposition but in some exposures it appears to have been tilted since deposition. All of the characteristics and relations of these masses are the same as those of No. 2 except that these are not covered by till of the same age. In several exposures which have been overridden by a younger ice sheet, the surface gravel is plowed up and the beds are folded by the overriding ice. The largest mass of gravel of this type observed is 55 feet thick and more than 75 yards in average horizontal diameter (see figure 21). (5) Kames, sometimes elongate and eskerlike, and masses of gravel in kamelike hills have been observed in many places, especially on the surface of the Iowan and Mankato drifts. The gravel of these masses may be similar to that of masses described in Nos. 2 and 4, or the beds may show slumping along the margins of the deposit. The bases of these deposits may be on the upper drift surface but generally extend several feet into the till. (6) In some places the deposits of outwash gravel have been observed on the surface of the drift. These may be either in depressions or on the flat surface. However, none of them show slumping or tilting of beds subsequent to deposition. (7) Distinctly different from the types of gravel described are those which occur as outwash terraces along streams. These terraces occur either along the valleys which were developed before the advance of the glacier or along consequent streams on the freshly deposited drift surface. This material is well stratified, generally in horizontal beds. In most of the exposures the base of the gravel is below the ground water surface and the underlying material is concealed, but in those where it is exposed the gravel generally overlies till of the same age. The gravel is overlain by unstratified silt or loess of practically the same age as the gravel and in some exposures the overburden is interbedded with the gravel showing that they were being deposited at the same time. In no exposure was the gravel overlain by till of the same age. (8) In extinct Lake Calvin, lacustrine deposits form terraces along the streams which have cut their valleys in these lake beds. The lacustrine beds consist of well-stratified sand and silt which were deposited under quiet water conditions. (9) Loveland interglacial gravel forms terraces along some of the valleys of southern and western

Iowa. These materials represent fluvial deposits along streams. In those exposures where the base of the gravel is exposed it overlies oxidized and unleached Kansan till. These gravel deposits are covered by Peorian loess in most of the exposures and in one place the loess and gravel are interbedded. In a discussion of the origin of these nine types of deposits several hypotheses will be introduced. The first six types of gravel will be discussed together and the last three types will be taken up individually.

In discussing the first six types of gravel deposits, the following hypotheses will be considered: (1) They are outwash and kamelike masses deposited on the surface of the drift at the margin of the retreating glacier. Some of them were deposited as outwash in depressions while others were deposited on the flat drift surface. (2) They are outwash and kamelike masses deposited as in No. 1 and later buried by till which was deposited by a readvance of the ice front. (3) They are older gravel deposits on the surface over which the glacier advanced, picked up in a frozen condition and later deposited as gravel boulders, within the till. (4) They are gravel deposited in front of the advancing glacier, then picked up and deposited as gravel boulders, within the till. (5) They are gravel deposited in great moulins, tunnels, and other cavities within an active glacier and later let down to their present position as the ice melted. (6) They are deposition in great moulins, tunnels, and other cavities within stagnated ice, either let down to their present position as the ice melted or originally deposited in their present positions. No one of the preceding hypotheses is capable of explaining the origin of each type of gravel nor are all the types of gravel limited to a single hypothesis to the exclusion of the others.

Hypothesis No. 1 is most commonly used to explain the origin of those gravels, at and near the till surface, deposited during glacial retreat. The streams flowing through tunnels in the glacier were subjected to the pressure of the surrounding active ice and consequently had a greater transporting power than they had when they emerged into the open channels beyond the margin; thus the streams were forced to deposit part of their load as soon as they left the glacial tunnels. If the till surface was flat, the gravel was deposited as a kamelike mound on its surface, but if irregular, the gravel was deposited in a depression and may or may not have been piled up in kamelike mounds. These depressions were the result either of uneven distribution of the till or of the melting of a block of ice which had been deposited within the till. The only notable difference between those deposits in depressions and those on a flat surface is their present position either entirely above the till surface, partly below the till surface, or entirely below the till surface. If an appreciable amount of gravel is deposited on the uniform surface it will form a kamelike mound. If the gravel is deposited within a depression it may be partly or completely below the till surface as an irregular mass within the till, or after the depression is filled, further deposition might form a kamelike feature. In this case the base of the kame would be within the till. This hypothesis alone cannot explain pockets or lenses of gravel buried within a single till sheet.

The second hypothesis is the same as the first except that it allows also a later readvance of the melting glacier, its deposition covering the gravel with till. This would explain the origin of those masses buried within the till sheet.

These hypotheses together can explain outwash and kame deposits on the till surface and irregular masses of gravel within the till, both at its surface and completely buried. Although hypotheses Nos. 1 and 2 can explain the deposition of each type of gravel within the till, except the gravel boulders, it is difficult to explain certain features such as the deposition of thin beds and lenses of sand and gravel interbedded with the till. If a readvance of the ice is necessary to explain the deposition of the till, there must have been many minor rapid advances and retreats of the retreating margin. Furthermore, it is inconceivable that the glacier could pass over these freshly deposited sands and gravels and not disturb the structure or remove part of the deposit. In several exposures of Kansan gravel, the Iowan glacier which advanced over them has removed the gravel from the surface and folded some of the beds. Assuming deposition within stagnated ice, interbedded till and gravel could be deposited without minor advances and retreats of the ice margin.

The third hypothesis explains the origin of some of the irregular masses of gravel buried within the till which have a different lithology than the till and may be leached although within unaltered till. These represent older gravel deposits occupying a position on the drift surface over which the glacier advanced. Large fragments of this deposit were picked up, transported, and deposited in a frozen condition as "gravel boulders." These gravel boulders range in size from a few inches to more than 25 feet in diameter. Gravel of this type — even though deposited originally in horizontal beds — may, following transportation, be redeposited with the beds tilted in any position. Having been picked up from the surface over which the ice advanced, and transported only a short distance, it would commonly occupy a position in the lower part of the glacial load and consequently be deposited within the lower part of the till sheet.

The fourth hypothesis differs from the third only in that it postulates that the gravel was deposited originally at the margin of the advancing glacier. The lithology of this gravel would be the same as that of the enclosing till, and the till and gravel would have undergone comparable alteration. This explains the "gravel boulders" within the till which cannot be explained by the third hypothesis.

The fifth hypothesis would have the gravel deposited in great moulins, tunnels, or other cavities on or within the ice. As the ice melted, these deposits were let down along with the rest of the glacial load. If they had been deposited high within the glacier, above the glacial load, they would be let down on the surface of the till. If they were deposited originally near the base of the glacial load they would form a mass near the base of the till. In all cases their position within the till would be determined by their position of deposition within the ice in respect to the glacial load. During lowering of, or during further transportation after deposition, the mass might be tilted in a plane different from that of original deposition.

Carman discusses this hypothesis as explaining one of the possible origins of certain gravel deposits of northwestern Iowa.[60] However, he states: "The chances of such deposits being formed were probably greatest near the edge of the glacier where the ice was thin, and where holes could extend even through to the ground beneath." From this statement it seems that he had difficulty in conceiving deposition to any extent within the active ice and probably thought of the thin ice near the margin as more or less stagnated and inactive.

The sixth hypothesis differs from the fifth only in that it assumes deposition within inactive "stagnated" ice along the margin of the glacier.

60 Carman, J. Ernest, Further Studies on the Pleistocene Geology of Northwestern Iowa: Iowa Geol. Survey, Vol. XXXV, p. 101, 1931.

As a result of studies in the Connecticut valley, Flint [61] explained the origin of the terraces on the basis of stagnation of the Wisconsin glacier. In a more recent report he describes evidence of stagnation in northwestern Illinois.[62] White [63] has described glacial stagnation in Ohio. In Europe stagnation has also been recognized by various students, including Koernke, B.,[64] Von Bülow, K.,[65] and Woldstedt, P.[66] Andersen [67] in a recent paper discusses the melting of the last ice sheet in Denmark and the origin of certain glaciofluvial deposits. He accounts for the origin of the glaciofluvial deposits on the basis of a stagnated ice border around the active ice center. Within this stagnated ice, tunnels and cavities would remain open, unaffected by ice movement.

In discussing the hypotheses for the origin of the glaciofluvial deposits in Iowa, one should not omit the possibilities of deposition within a stagnated ice sheet. The greatest difficulty in explaining gravel deposition by the fifth hypothesis (within moulins, tunnels, and cavities within the active glacier) is overcome in the sixth hypothesis, in which the ice is stagnant. Since deposition by both hypotheses is in the same manner, the merits of one can be brought out along with a discussion of the difficulties of the other.

Within an active ice sheet, the internal pressure-producing movement would operate against least resistance, tending to close any openings which might develop. But assuming that some streams were able to maintain channels, the pressure and likewise the transporting power would be so great that deposition of sand and gravel could not take place along the stream courses within active ice. However, if streams of this type existed, the release of pressure at the margin of the active ice would cause decrease in transporting power; thus gravel would be deposited outside this active ice margin. This gravel would be included under the first hypothesis. No doubt streams flowed on

61 Flint, R. F., Pleistocene Terraces of the Lower Connecticut Valley: Geol. Soc. America, Bull. 39, pp. 955-984, 1928. The Stagnation and Dissipation of the Last Ice Sheet: Geog. Review, Vol. XIX, pp. 256-289, 1929. The Glacial Geology of Connecticut: Conn. Geol. and Nat. Hist. Survey Bull., Vol. XLVII, 1930.

62 Flint, R. F., Glaciation in Northwestern Illinois: Am. Jour. Science, Vol. XXI, pp. 244-439, 1931.

63 White, George W., An Area of Glacier Stagnation in Ohio: Jour. Geol., Vol. XL, pp. 238-258, 1932.

64 Koernke, B., Letztglazialer Eisabbau und Fluszgeschichte im Nördlichen Ostpreuszen und sienen Nachbargebieten: Zeitschrift der Deutschen Geologischen Gesellschaft, Vol. 82, pp. 14-32, 1930.

65 Von Bülow, K., Die Rolle der Toteisbildung beim letzten Eisrüchkzug in Norddeutschland: Zeitschrift der Deutsch. Geol. Gessel., Monatsber., Vol. 79, pp. 273-283, 1927.

66 Woldstedt, P., Das Eiszeitalter: Stuttgart, 1929.

67 Andersen, S. A., The Waning of the Last Continental Glacier in Denmark as Illustrated by Varved Clay and Eskers: Jour. Geol., Vol. XXXIX, pp. 609-624, 1931.

and near the surface of the glacier; but even if they found an available load, and deposited gravel along their courses, it would be let down on top of the till and could not form masses within the till without another glacial advance to deposit a layer of till over the gravel.

If it is assumed that the margin of the ice was stagnant, the pressure tending to close any openings within the ice would be relatively small, and moulins, channels, and cavities once developed could exist. Gravel deposited within this stagnant ice would be let down along with the rest of the glacial load as the ice melted, its final position within or on the till depending upon its position at the time of deposition in respect to the glacial load. If deposited above the glacial load it would be let down on the surface of the till but if within the load, it would be included within the till.

From the preceding discussion of the six hypotheses, it is evident that no one can explain the origin of all types of upland gravel.

The first hypothesis explains outwash gravel with no difficulty and masses of gravel within but at the surface of the till can be explained if one assumes a depression in the surface of the till into which the gravel was deposited. The second hypothesis explains those deposits buried within the till, their deposition originally being on the surface of the till then later buried by a readvance of the ice. The third and fourth hypotheses explain "gravel boulders" picked up from the surface over which the ice advanced and deposited within the till. The fifth hypothesis seems impossible. The sixth hypothesis explains each type of gravel except those explained by the third and fourth hypotheses. In fact, deposition by this hypothesis eliminates difficulties involved in the explanation by the other hypotheses.

The glacial outwash terrace deposits in Iowa were deposited during the Iowan and Mankato glacial time. The Iowan glacier advanced over the freshly eroded surface developed on the Kansan drift plain during the Loveland interval. The thin Iowan drift sheet deposited within the area covered by the Iowan ice did not fill these valleys but spread over the surface like a blanket. The streams flowing from the melting ice followed these partially filled valleys. Since the valleys were not filled by Iowan deposition, the Mankato glacier also advanced over an irregular surface upon which well-developed drainage lines still existed. Within the Iowan area the valleys were partly filled by Iowan drift but beyond the Iowan margin no drift was deposited in these pre-Iowan valleys. The drift sheet deposited by the Mankato ice was thicker than that deposited by the Iowan and filled many of the more shallow valleys, but some of the larger ones remained open. Where unfilled by Mankato drift, the streams followed these previously developed drainage lines, but in other places the streams flowed in broad, shallow valleys developed upon the newly deposited irregular drift surface.

The streams flowing through the glacier were transporting a maximum load. As they flowed out of the ice, the release of pressure and increased friction decreased the velocity, which necessitated the deposition of the coarsest material. This did not mark the final deposition, because as the increased volumes of water flowed down their restricted valleys all of the processes of transportation and deposition were active. The fluctuation of the water supply, the wear on the load, and all the variations in the channel brought about continuous change in load. The only coarse material transported directly for any long distance was that carried by the floating cakes of ice. Other coarse material was moved by rolling or saltation. Aside from the glacier the only other source of material was in the valley itself, which in some cases afforded abundant material. As the glaciers advanced, they picked up the loose material from the surface and later deposited it as till. The streams flowing over this till surface found only a small amount of gravel and sand which had not been reduced to fine dimensions during transportation within the ice. The softer material, including limestone, had suffered most. Thus limestone fragments in the till were only moderately abundant in relation to the other fragments which had been transported greater distances. The wear of the stream upon its load destroyed the less resistant material most readily just as did the glacier. This also decreased the percentage of limestone in relation to the other rocks.

A study of exposures of gravel shows that some contain no limestone while others contain a high percentage. Some of the limestone was removed by leaching but extreme variations of this type could be based only upon the type of material deposited. Furthermore, if an abundance of limestone had been deposited in those exposures in which it is now absent, and was removed by leaching, the contraction of the beds resulting from the removal would destroy the perfect stratification often observed. As previously stated, the gravel is from only two sources: 1) that carried out from the glaciers by the waters from the melting ice, 2) that removed from the valleys through which the streams flowed. The kinds of material supplied from the glacier should be relatively constant. Likewise, where the stream flows over the till the gravel obtained should be similar to that coming from the glacier; but aside from the till the streams sometimes encountered resistant ridges of limestone along their courses.

Those exposures of gravel showing an abundance of limestone are usually located along the valley near exposures of limestone along the valley wall. This leads to the conclusion that the gravel along the valleys is not derived directly from the glacier; much of it comes from local sources. Also, in most cases the limestone material which forms the terraces is like that of the limestone exposures nearby and the angular shape shows that it has not been transported far by the stream.

Most of the valley outwash terraces represent glaciofluvial deposition in the bottom of the valley filling it to the level of the present terraces, which have been partly removed by the subsequent erosion of streams which incised their valleys in these flats. The surface of these old plains is marked only by the terraces which stand above the streams. However, in a few places along some of the deeper, more constricted valleys, terraces occur high up along the valley wall and sometimes with their upper surfaces almost at the level of the upland. In those exposures where the underlying material was observed the gravel of the terrace overlies fresh Mankato till or Peorian loess. These terraces are of two possible origins: they represent either outwash terrace gravel that filled the valley to this height and later was all removed except the narrow patches along the valley wall, or outwash gravel deposited along the margin of the valley after the ice had melted from the higher land but still remained in the valleys. In the latter case the ice would form one side of the valley and the major valley wall the other side. There seems to be little question as to which is the more logical assumption. These terraces stand higher than those in the broad open valleys along the same stream, suggesting deposition of gravel to greater depths within this part of the valley. Such deposition is difficult to explain. Even if this valley was so constricted that it could not accommodate all of the drainage but backed the water up to this level, the height of the water in comparison to what it would be on either side would make this an eroding rather than a depositing stream. Furthermore, there are no comparable terraces along the broader parts of these valleys. There are no serious objections to the hypothesis that these terraces along the sides of the valleys were formed before the ice filling the valley had melted. Most of the outwash terraces are not of this type but represent glaciofluvial deposition in the bottoms of the open valleys in front of the retreating glacier.

The Illinoian glacier advanced into the southeastern part of Iowa, damming the Mississippi river and several smaller streams within this part of the state. This ice dam forced the Mississippi to follow a channel marginal to the ice, and 10 to 30 miles west of its present course. The waters of the Mississippi and the smaller streams across whose channels it had flowed — the Maquoketa and Wapsipinicon — all flower into the Cedar river at Moscow. As the valley of the Iowa-Cedar river also was blocked by the Illinoian ice sheet, the valley formed a great basin in which the now extinct Lake Calvin was formed. Water flowed into this basin from the melting Illinoian glacier and from all of the previously mentioned streams — the Mississippi, Maquoketa, Wapsipinicon, Cedar, and Iowa. The water level was raised in this basin until it reached the height of the now abandoned outlet southwest of Columbus Junction.

Each source of water supply for this lake carried in and deposited sand and silt in the quiet water of the basin. Three terraces have been formed in the basin as shown in figure 29: the high, intermediate, and low. After extensive study of this lake basin, Schoewe [68] concluded that the two upper terraces are lacustrine deposits of simultaneous origin and the lower terrace is glaciofluvial outwash from the melting Iowan glacier.

Except in a few places, the high terrace is confined to the Iowa river valley arm of the lake basin and the intermediate terrace to the Cedar river arm. This difference in elevation is explained on the basis of a greater supply of sediment in the Iowa river arm than in the Cedar river arm in relation to the size of the valley basins. Although the Cedar river valley was much wider than the Iowa river valley, the latter had more large tributaries, which brought in material and thus filled the Iowa river valley to a higher level than the Cedar river valley. The only high terrace remnants within the Cedar river arm are within the main tributaries, which were bringing in considerable material.

The lower terrace consists of coarser material than the two upper

68 Schoewe, Walter H., The Origin and History of Extinct Lake Calvin: Iowa Geol. Survey, Vol. XXIX, pp. 49-222, 1924.

terraces. Instead of having a structure characteristic of quiet water lacustrine deposition, it has that of river terrace deposition, including cross-bedding and lens-and-pocket structures. The origin of this terrace can be traced directly to glaciofluvial outwash from the melting Iowan glacier.

The Loveland gravel is within the valleys cut in the Kansan drift sheet during the Loveland interval. Where differentiated, the gravel is within valleys entirely within the Kansan drift area and could not represent outwash from the younger Iowan or Mankato glaciers. The only possible source of this gravel is the erosion of the drift. It is believed that as erosion continued, the finer material was carried out, leaving the coarser material concentrated along the valleys. However, the thick deposits in some of the valleys — especially small valleys like Deep Creek, in Plymouth county — are difficult to explain. Furthermore, although all of the Loveland gravel of northwestern Iowa appears to have been deposited at the same time, the loess on the uplands differs in the amount of weathering and appears to have been deposited at different times during the interval. Likewise a comparison of the gravel of southern Iowa with that of northwestern Iowa would suggest that they represent deposition during different parts of the interval.

At the present time the only definite statement that one can make is that the Loveland gravels were derived from the erosion of the Kansan drift during the Loveland interval and were deposited in their present positions before the deposition of the Peorian loess which overlies them in many places.

CONCLUDING STATEMENTS

The field and laboratory studies presented have extended over many years. The senior author has spent much time during the past 25 years in studies of different phases of the Pleistocene deposits in Iowa, and has examined hundreds of sections distributed throughout the state. The junior author has assisted in the field and collected samples from many exposures of each type and age of gravel from the Pleistocene deposits of the state. These samples were subjected to sedimentary studies in the laboratory in the hope that some laboratory procedure would prove valuable in differentiating gravel of different ages and in interpreting their origin.

In the laboratory the generally accepted method of mechanical analysis was used, with some necessary modifications. The samples were split into a convenient size, 40-300 grams, depending on the clastic texture of the material. In many of the non-calcareous samples iron oxide coated the grains and cemented some of them together. This was removed by boiling the sample five minutes in a 15 per cent solution of hydrochloric acid and then adding sufficient stannous chloride to reduce the iron oxide so that it passed into solution. The material in solution and the size grades finer than 1/32 millimeter in diameter (never exceeding 3 per cent of the sample) were removed by decantation. The removal of the iron oxide coating was necessary to enable accurate sieving and optical studies of the shapes of the grains. The mechanical analyses were made by sieving and subsidation. The percentage of rounding was determined for each sieved size grade between 1/16 and 32 millimeters in diameter, the smaller grades being studied with the microscope. The lithology was determined from pebbles between 16 and 32 millimeters in diameter. Definite determinations of the different varieties of crystalline rocks, many of which were much weathered, was not attempted; only the main groups were differentiated. In making the lithologic analyses, calcareous concretions and clay-balls were not included, since they were not regarded as primary material.

From these laboratory studies only negative results were obtained. The clastic texture of the gravel varies widely, not only between different exposures but also within a single exposure. Even within a terrace deposited by a single stream, almost every bed has a different texture. Mechanical analyses, even when made from representative samples of gravel which were separated by only a few yards of horizontal distance, may bear practically no resemblance to each other. The thickening and thinning of beds which resulted from differences in conditions of deposition along the stream course, and the differences in kind and origin of material, are all active in producing lack of uniformity. Inasmuch as gravel deposits of like types were deposited under similar conditions, no diagnostic differences in clastic texture would occur within those of different ages. As long as there is no basis for determining the distance that upland deposits have been transported, or the amount of rounding either by the ice or before it was picked up by the ice, and further since there is no reason to believe that the amount of rounding was comparable even in like deposits of the same age, the percentage of rounding would be of no value in their correlation. It was hoped that along the valleys the percentage of rounding would enable one to determine the distance the gravel had traveled, and that thus it would be possible to differentiate between gravels of different ages within the same valley. However, this could not be done. The lithology of the gravel, like that of the till sheets, is similar for all ages, and only within local areas can differentiations be made on this basis. The Pleistocene gravel deposits in Iowa are of four distinct types, as has been determined by field investigations. These are: (1) upland gravel, deposited either within or on the surface of the till as the ice melted; (2) terrace gravel, deposited as outwash in the valleys beyond the margin of the melting ice; (3) interglacial terrace gravel, deposited in the valleys during the Loveland interval; and (4) lacustrine sand and silt, deposited in "Extinct Lake Calvin."

Upland gravel was deposited during the melting of each of the ice sheets which invaded the state. These occur in several positions: (1) irregular masses picked up in a frozen condition as gravel boulders and deposited intact within the till; (2) irregular masses buried within the till but representing glaciofluvial gravel deposited in place as the till was deposited; (3) irregular masses similar to those of number 2, but at the surface of the till sheet; (4) outwash gravel on the surface of the till; and (5) kamelike knolls on the surface of the till. The first type of gravel may have been deposited either in front of the advancing glacier or during an earlier part of the Pleistocene period. The latter four types are glaciofluvial gravel deposited either as the ice margin remained stationary or retreated.

The glacial terraces were deposited during the melting of the Iowan and Mankato invasions of the Wisconsin glacier. These terraces are along the valleys within the area covered by that ice sheet and extend farther down the valleys across older drift areas. Along those valleys which have received terrace gravel of more than one age, it is generally impossible to differentiate the ages, but where possible, the determination is largely on the basis of relationship to associated materials. Terrace gravel deposits along such streams have been described as undifferentiated gravel.

The Loveland interglacial gravel was deposited during the Loveland interglacial interval in those valleys developed during that interval. It is not possible to state during what part of the interval the gravel was deposited, but no doubt the deposition represents a considerable range of time.

The Illinoian glacier, which invaded southeastern Iowa, dammed the Mississippi river and several of its tributaries and forced them to flow around the west margin of the glacier. The Iowa and Cedar rivers were blocked and their valleys afforded a large basin into which these waters flowed to form Extinct Lake Calvin. All of the streams that flowed into this basin, either from the melting Illinoian glacier or from the area drained by these river systems, carried material which formed thick deposits in the bottom of the lake. Just before the advance of the Iowan ice the lake was drained and streams then cut their valleys into the lake beds which now stood as broad, relatively flat plains.

In the field, the differentiations of the upland gravels are based upon the alterations the deposits have undergone and upon their relations to other deposits. Oxidation has practically no significance since it varies greatly within different exposures of the same age, and is as pronounced in a few of the exposures of the youngest gravel as in the exposures of the oldest gravel. Weathering and disintegration of rocks are likewise variable, since many of the rocks were much weathered even before the final deposition. The only alteration of real significance in making differentiations is the leaching of carbonates, which is relatively uniform throughout the exposures of the same age, which occur at similar positions in respect to the surrounding deposits. The Nebraskan gravel deposited at the surface of Nebraskan till — the

Nebraskan gumbotil horizon — has been leached during the Aftonian age to a depth of at least 20 feet. If the gravel were buried within the till the leaching would be much less or even lacking, depending upon the depth. The Kansan gravel, deposited at the surface of the Kansan till, was leached to a depth of about 30 feet during the Yarmouth age. In the Illinoian gravel leaching during the Sangamon age was to a depth of about 12 feet. Since deposition, the Iowan gravel has been leached to a depth of about 5 1/2 feet, and the Mankato only 30 inches. Even though the depth of leaching is quite uniform in upland gravels, in the terrace gravels it may vary, either because of greater freedom of ground water circulation or because of the absence of carbonates at the time of deposition. Some exposures of Iowan terrace gravel are free from carbonates to a depth of more than 15 feet, but most of the exposures are leached to about the same depth as the Iowan upland gravel.

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