IOWA
GEOLOGICAL SURVEY

VOLUME XXXV

Annual Report, 1929

with

Accompanying Papers

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THIRTY-EIGHTH ANNUAL REPORT OF THE STATE GEOLOGIST

IOWA GEOLOGICAL SURVEY,
DES MOINES, DECEMBER 31, 1929.

To Governor John Hammill and Members of the Geological Board:

GENTLEMEN: Six papers are herewith submitted to the Board with the recommendation that they be published as Volume XXXV—the Thirty-Eighth Annual Report of the Iowa Geological Survey. The titles and authors of the papers are as follows:

Further Studies of the Pleistocene Geology of Northwestern Iowa, by J. Ernest Carman

The Dakota Stage of the Type Locality, by A. C. Tester

The Stratigraphy of the Kinderhook Series of Iowa, by Lowell R. Laudon

The Natural Molding Sands of Iowa, by John E. Smith

On a New Specimen of a Paleoniscid Brain from Iowa, by Roy L. Moodie

Mineral Production in Iowa in 1928 and 1929, by James H. Lees.

A report entitled the Pleistocene geology of Northwestern Iowa by Dr. J. Ernest Carman was published by the Iowa Geological Survey in Volume XXVI (1917), pages 233 to 445. Later work in northwestern Iowa has shown that those parts of the report of 1917 having to do with the Kansan drift region, as there interpreted, should be revised in order to recognize an Iowan drift region in the eastern part of the area there called Kansan. The recognition of this Iowan drift region required many changes of interpretations and much of the data presented in Chapters III, IV and V of the report of 1917 is here presented again in rearranged form and with new interpretations.

In the present report Chapter I summarizes that part of the earlier work in northwestern Iowa which bears directly on the area here called Iowan. Chapter II treats the Iowan drift region including certain associated gravels. Chapter III treats the Kansan drift region. Chapter IV deals with the loess and Chapter V with the gravels in the valleys, chiefly of the Iowan drift region. The report closes with a summary of the conclusions reached concerning the various subjects treated in the report.

The Iowan drift region of northwestern Iowa as recognized in this report includes a questionable area which has been variously interpreted by earlier workers in this region as Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan or Kansan. During the progress of the work upon which the report of 1917 was based this area was differentiated and its limits determined, but because of its indefinite characteristics, and also because of differences of opinion as to its correlation, it was finally decided not to recognize it as separate from the Kansan drift region. It is an elongate north-south area lying between the Des Moines lobe of the Wisconsin drift sheet on the east and the more positive Kansan drift region along the west line of the state. Its extent in Iowa is about 2,000 square miles and it continues northwestward across southwestern Minnesota to Watertown, South Dakota. Southward the area terminates at the south line of Sac county.

The characteristics of the Iowan drift topography are faint and rather indefinite. The drainage pattern is roughly dendritic and a general view suggests an erosional topography. However, a closer study shows that the slopes are not long, smooth slopes due to erosion but are somewhat uneven and billowy, and the valleys are more or less obstructed. The interpretation is offered that this region had an erosional topography developed in the Kansan drift and that the thin Iowan drift sheet merely veneered this erosional topography. It thus results that the greater relief features are erosional and the minor features are constructional. It is a masked erosion topography. The characteristics of the Iowan till are so like those of the Kansan till that the two tills cannot in many exposures be definitely separated. The till of the Iowan region has much gravel associated with it. Some of the gravel is in masses in the till, some is in low mounds at the surface, some is interbedded with the till, and some is in bedded deposits in the valleys. These several types of gravel, which appear to have had a common origin, are discussed and interpreted. The till and gravels of the Iowan region are overlain by a thin layer of loess which is interpreted as Peorian in age. This loess is continuous with the Missouri River loess to the west.

At a few places in the Iowan drift region a till, beneath the Peorian loess, rests upon older loess, silt and sand deposits which are younger than the erosion of the Kansan till and are interpreted as Loveland. These exposures fix very definitely a post-Loveland, pre-Peorian till in northwestern Iowa. It is assigned to the Iowan age and correlated with the Iowan of eastern Iowa on the bases of similar topography, similar relations to the Kansan below and to the overlying mantle of loess, and similar geographical positions with respect to the later Wisconsin drift region.

The paper by Dr. A. C. Tester entitled The Dakota Stage of the Type Locality is the result of several years study in the field and laboratory. It deals primarily with the exposures of Dakota rocks in Woodbury and Plymouth counties, but it also describes in detail the rocks of the same age in Dakota county, Nebraska, and makes some comparisons with other localities in Iowa, Nebraska and Kansas.

The first chapter contains an analysis of all previous work done in the area or in adjacent areas which have a bearing on the type section.

The literature on the subject dates to the first decade of the nineteenth century when Lewis and Clark, Nuttall and others made their explorations. The last work of significance was done during the closing years of the nineteenth century and the first part of the twentieth century by Calvin, Bain, Gould and others. Since this work many new ideas have developed and the question of the age and stratigraphic relations of the Dakota has become one of considerable interest.

Following the detailed descriptions and interpretation of ten stratigraphic sections the author describes other exposures of the Dakota in southwestern Iowa and in Nebraska and Kansas. The exact stratigraphic position of the marine invertebrate fossils in Iowa and Nebraska is related for the first time in the study of these formations. A comparison is made of the fauna as found in this locality with that of the Mentor-Kiowa of Kansas, and the close relationships of types and age are stressed.

No stratigraphic or erosional break occurs between the Dakota and Graneros of Iowa, and the fauna of the Dakota is of the lower Cretaceous type, which is much older than previously supposed for the Iowa formations. This fact suggests that the lower Cretaceous of the northern interior is a *series* closely related to the upper Cretaceous Series. The Dakota is described as the upper *stage* of the lower *series*. Lower stages of the Cretaceous are not known in Iowa though they do occur farther south.

It is believed that the sea advanced into Iowa from the west and southwest. Petrographic analyses of the sandstones show appreciable amounts of quartzite, basic feldspars and chert grains. It is believed that a land mass including northwestern Iowa and southwestern Minnesota furnished much of the materials present in the Dakota sandstone beds. The rivers carrying this material had a general west or southwest course, draining from the landmass of Siouxia.

Dr. Lowell R. Laudon in his paper entitled The Stratigraphy of the Kinderhook Series of Iowa states that the Series in Iowa contains three formations, the Maple Mill at the base, followed by the English River, and capped by the Hampton formation. The term Hampton is proposed for the Kinderhook members above the English River formation. It is named after the city of Hampton in Franklin county, around which the beds are best exposed.

The Maple Mill formation consists mainly of shales and fine silts. Its distribution is mainly in southern Iowa. It is correlated with the Chattanooga of the standard Mississippian section.

The English River formation consists mainly of blue to yellow quartz siltstone. It is exposed mainly in southeastern Iowa. The northernmost exposure is at LeGrand, Iowa. It is very fossiliferous throughout and is correlated definitely with the Hannibal formation of Missouri. It is separated from the overlying Hampton formation by a marked angular unconformity. Its relation to the underlying Maple Mill formation is not definitely known.

The Hampton formation consists of a varied group of mainly calcareous sediments. Dolomites predominate by far. It includes also oölitic limestone, lithographic limestone, limestones of various colors, chert, and a little sandstone. The Hampton formation has been divided into members on the basis of both its lithology and its fauna. These members have been traced areally throughout the belt in which the Kinderhook is exposed in Iowa. The Hampton formation is unconformably overlain by the Burlington limestone.

The results of Doctor Laudon's investigation may be summarized as follows:

1. The Sheffield formation has been determined to be Upper Devonian in age and has been correlated with the Chemung of New York.

2. The Kinderhook formations have been found to be separated from the Sheffield formation by a marked angular unconformity and a very sharp faunal break.

3. The shale formation of southeastern Iowa (Maple Mill) and

the shale formation of north-central Iowa (Sheffield) are not of the same age.

4. The Sheffield formation has been identified as far south as Amana, Iowa.

5. The English river formation seems likely to be a marine overlap from the south and represents only the upper part of the Hannibal formation of Missouri.

6. The English River formation has been traced as far west and north as LeGrand, Iowa.

7. The English River formation is separated from the overlying Hampton beds by a marked unconformity and a marked faunal break. A fish tooth conglomerate marks this contact at one place.

8. The lower part of the Hampton formation is correlated with the Chouteau formation of Missouri.

9. The upper part of the Hampton formation (Maynes Creek, Eagle City, and Iowa Falls members) carries a fauna that has been derived from the Chouteau fauna. The fauna of these members, however, is probably younger than any part of the Chouteau of Missouri.

10. The Wassonville chert horizon has been found to be a very widespread horizon marker in the Hampton formation in Iowa.

11. The Alden limestone formation is separated from the underlying Hampton formation by a marked angular unconformity. The Alden limestone is correlated with the Gilmore City limestone (Humboldt Oölite) of Humboldt and Pocahontas counties. The limestone at Gilmore City carries a fauna which is definitely younger than any Kinderhook fauna but whose stratigraphic position has not been definitely determined as yet. For these reasons the Alden limestone has not been included with the Kinderhook.

The paper by Professor John E. Smith on The Natural Molding Sands of Iowa defines these sands as being "mixtures of sand, silt, and clay in such proportions as to make them adapted for use in various kinds of foundry work." This mixture must allow ready escape for the gases that form when the molten metal is poured into the molds and at the same time it must have sufficient bond strength to allow it to hold its shape in the mold. Professor Smith gives the results of tests on a number of molding sands from Iowa and a few from other states and then proceeds to give descriptions of the deposits that he found in the various counties. Most of these are in eastern Iowa, but a few are west of Des Moines. They are found, not as a part of the bedrock, but as part of the loose mantle rock and are classified as flood plain deposits, lake deposits, glacio-fluvial and glacio-eolian deposits and eolian and residual deposits. Professor Smith concludes that "There is an abundance of nearly all kinds of molding sand in Iowa and some of each is now being used in the various foundries of the state. Our own sand should be used much more extensively instead of that shipped here from other states."

Dr. Roy L. Moodie in his short paper entitled On a New Specimen of a Paleoniscid Brain from Iowa describes a nodule which contained the fossilized brain of an ancient fish. This nodule was picked up on the Rock Island railroad track at Iowa City and so the exact locality where this fish made its home can not be known. Doctor Moodie first gives a historical review of writings on similar subjects and then discusses the primitive sturgeons with which this Iowa fish was allied. He states that the later relatives of these sturgeons gave rise to land vertebrates, to the air-breathing fishes and to the more modern bony fishes. He then describes the Iowa nodule and discusses the character of the brain and of the type of fishes from which it was derived. Doctor Moodie's paper is a unique and important contribution to the study of fossil life in the upper Mississippi valley.

The mineral production in Iowa during 1928 and 1929 is discussed by Dr. James H. Lees. The mineral industry showed some gains in both of these years although in neither year was the increase a large one. Quantities and values in 1928 were greater in cement, coal and stone produced and values in sand and gravel were somewhat greater, although the quantities produced were somewhat less than in 1927. Clay and gypsum products showed declines, quite marked in the case of gypsum, only slight in the case of clay products. The production of Portland cement was 31 per cent greater in 1928 than in 1927, and shipments were 22 per cent greater. Six plants were working, as the Gilmore City factory, which had been idle for two years, was put into operation. A marked concentration of clay plants is noted, as only 48 plants were at work in 1928 in contrast with over four hundred in earlier years. Only one pottery reported production—that at Bellevue, making red flower pots. The coal industry began to look up after the disastrous strike of 1927, and it increased production by over 700,-000 tons. Even then, the production was less than one-half the output of peak years. Marion county now holds the leading place which Monroe held for so long. The results of an extensive series of analyses of Iowa coals are given, both by mines, by districts and by the geologic horizons from which they came.

The gain in output during 1929 was not equal to that made during 1928, but at least it indicated that the mineral industry was progressing. Shipments of cement from Iowa factories were a little less than in 1928, and prices were slightly lower. This was despite the growth of the state's road making program. The value of clay products marketed exceeded that of 1928 by over $700,000 and the value of coal sold was more than a million dollars above the value for the year before. The decrease in building during 1929 seems to be responsible for the fact that gypsum sales fell off by $687,000, and perhaps the same cause may be blamed for the lessened output of limestone and lime and of sand and gravel so far as these materials entered into building construction other than road building. The report includes lists of operators in the state.

The following table summarizes production during 1927, 1928 and 1929.

Product	1927	1928	1929
Cement	$ 9,124,405	$10,734,838	$ 9,781,159
Clay wares	5,194,780	5,048,774	5,791,175
Coal	9,304,000	10,525,000	11,948,000
Gypsum	6,713,497	5,355,214	4,668,856
Stone and lime	1,267,033	1,742,252	1,560,066
Sand and gravel	1,839,176	2,094,955	2,211,752
	$33,442,891	$35,501,033	$35,961,008

In November of 1928 an oil prospect well was begun on the Nodaway river bottoms about four miles south of Clarinda. As this well has attracted much attention among laymen and oil experts, mention of it is added to this report. Interest is attracted to this well by several factors. In the first place its depth of 4,671 feet makes it the deepest in the state by over 1,200 feet. Then too it is located in that part of the state whose underground geology is least known, owing to the fact that the strata lie deeper here than in any other part of the state. This is because of a great basin or trough that bows the rocks far down into the earth, although these same rocks come to the surface farther east and northeast. It has been the hope of oil producers that the western interior oil fields might be shown to extend into southwestern Iowa, but so far this has not been demonstrated. As the promoters of the well sent the Survey a very complete set of samples of the drillings it was possible to make a careful study of the strata penetrated. The results of this study will be published by the Survey in the near future.

In Volume XXXIV of the reports of the Survey the Director and his research assistant, Doctor Apfel, published a paper entitled "The Pre-Illinoian Pleistocene Geology of Iowa." In the closing paragraph is the following statement: "Although much has been accomplished by the many persons who have contributed to our present knowledge of the Pleistocene geology of Iowa there are yet many unsolved problems pertaining to the tills, gumbotils, gravels, peats, loesses, life, and other features of the glacial and interglacial deposits. In the future new facts and new interpretations of deposits of Pleistocene age will be presented, and as in the past new facts and interpretations will develop renewed interest and stimulate increased effort in unraveling the fascinating history of the Pleistocene deposits of our state and of other states."

More recent papers by the Director have included "Contributions to the Pleistocene Geology of Iowa," which appeared in Volume 36 of the Proceedings of the Iowa Academy of Science; "The Relative Ages of the Iowan and Wisconsin Drift Sheets," published in Volume 21 of the American Journal of Science; and "The Classification and Duration of the Pleistocene Period." The last named paper will appear in the 42d Volume of the Bulletin of the Geological Society of America. In this paper under "Concluding Statements" the most significant features of the paper are summarized as follows:

"Deposits of the Pleistocene or Glacial Period have been subjected to detailed study in America for more than fifty years. In the Mississippi Valley in particular the records of this most fascinating chapter in the earth's history have been remarkably well preserved and thoroughly investigated. In fact, this area has been made a classic one as the result of the researches of T. C. Chamberlin, McGee, N. H. Winchell, Leverett, Calvin, and many other geologists. Here evidence has been found which is conceded to be the most reliable in interpreting the history of the Pleistocene, in classifying the deposits of this geological system, and in estimating the duration of the Period.

In this paper the classification and the duration of the Pleistocene Period have been discussed. It was pointed out that when the most significant facts of Pleistocene history are analyzed critically in relation to what might be considered as a logical classification it is evident that from the time of the advance of the first ice-sheet, the Nebraskan, to the retreat of the last ice-sheet, the Wisconsin, there were recurrences of similar geological events with accompanying similar geological results. In other words, there were within the limits of the Pleistocene Period a succession of cycles, the most significant evidences of which are recorded in the deposits which were made during each cycle and in the changes which the deposits underwent before the coming of the succeeding cycle. Reasons were given for the interpretation that Pleistocene history involved four cycles. The judgment was expressed that it would seem to be desirable at the present time to bring together for distinct recognition in Pleistocene classification the sedimentary units which are the chief products of the cycles and to designate these cycles as epochs and the sedimentary units, each of which consists of the intimately associated glacial and interglacial materials formed during an epoch, as series.

A revised classification of the Pleistocene has been presented. It recognizes four epochs (series), each of which is divided into ages (stages) which continue to have the well established names of the present classification. New names have been chosen for the four epochs (series): Grandian, Ottumwan, Centralian, and Eldoran. These names were chosen from localities where the materials of the different stages have been studied in all their relationships and where they have areal distribution.

Estimates of the minimum duration of the Pleistocene in Iowa have been given. The evidence used in reaching judgments as to the durations of the interglacial ages was gained chiefly from extensive field studies in Iowa of relative depths of leaching of calcium carbonate in similar materials which throughout their times of leaching were similarly situated topographically and climatically. Leached gravels of known ages were compared. The differences in depths of leaching are the results of the differences in lengths of time to which the gravels were subjected to weathering agents. The depth of leaching of upland gravels in the Late Wisconsin drift was determined to be about 2 feet 6 inches. This leaching is the result of exposure to weathering since the retreat from Iowa of the Late Wisconsin ice-sheet, that is, through a period estimated to be about 25,000 years. With this rate of leaching of gravels as a unit estimates were made of the lengths of time involved in the leaching of other gravels of known ages. The results for Iowa as given in this paper are as follows: post-Late Wisconsin time, 25,000 years; post-Iowan time, 55,000 years; Sangamon interglacial time, 120,000 years; Yarmouth interglacial time, 300,000 years; and Aftonian interglacial time, 200,000 years. The combined durations of Aftonian, Yarmouth, and Sangamon interglacial ages, and of post-Iowan, total about 675,000 years.

The durations of the glacial ages in Iowa were estimated from present-day consensus of opinion as to the rates of advance and retreat of ice-sheets. For the retreat of the Late Wisconsin from Iowa the rate of one mile in ten years was adopted. The same rate was assumed for the advance of this ice-sheet into Iowa and also for the advances and retreats of earlier ice-sheets. The minimum duration of glacial time in Iowa was calculated to be about 30,000 years.

In accordance with the methods of evaluation adopted in this paper minimum interglacial time in Iowa was determined to be approximately 675,000 years and minimum glacial time in Iowa about 30,000 years, the combined estimates giving for the whole Pleistocene in Iowa a minimum duration of about 700,000 years. How far this estimate of the minimum duration of the Pleistocene falls short of the actual duration can not be determined from reliable quantitative evidence. However, it would seem safe to state that the Pleistocene involved probably a million years, possibly twice this length of time.

Evidence was presented also for the judgment that the 5 feet of gumbotil on the Illinoian till involved in its development about 70,000 years, the 12 feet of gumbotil on the Kansan till 250,000 years, and the 8 feet of gumbotil on the Nebraskan till 150,000 years. Gumbotil development was preceded in all cases by leaching of calcium carbonate.

As investigations of Pleistocene deposits continue into the future better and better standards of measurements will be established, and hence more and more accurate determinations of Pleistocene time will be made. The classification of the Period will no doubt have to be revised from time to time as further refinements of study of glacial and interglacial deposits enable more definite interpretations of their origin and history."

Respectfully submitted,

GEORGE F. KAY,

State Geologist.

FURTHER STUDIES ON THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

by

J. ERNEST CARMAN

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FURTHER STUDIES ON THE PLEISTOCENE GEOLOGY OF NORTHWESTERN IOWA

INTRODUCTION

The Iowa Geological Survey published in 1917 a report by the writer entitled The Pleistocene Geology of Northwestern Iowa.[1] This report of 1917 deals with an area of about 9,000 square miles comprising twelve entire counties and halves of four other counties; four rows from north to south, and three and one-half rows from west to east. The names and relative locations of these counties are given in figure 1.

In the report of 1917 Chapter I gives a summary of the earlier work on the Pleistocene of northwestern Iowa; Chapter II treats the Wisconsin drift region; Chapter III deals with the Kansan drift region, including all of northwestern Iowa west of the Wisconsin boundary; Chapter IV treats the gravels associated with the Kansan drift; Chapter V treats the gravels found in valleys of the Kansan region; Chapter VI discusses the Nebraskan drift; Chapter VII traces the geologic history of northwestern Iowa.

Later work in northwestern Iowa has shown that those parts of the report of 1917 having to do with the Kansan drift region, as there interpreted, should be revised in order to recognize an Iowan drift region in the eastern part of the area there called Kansan. The present report is, therefore, to replace Chapters III, IV and V of the report of 1917. The recognition of the Iowan drift region requires so many changes that it has been deemed advisable to present again, in rearranged form, most of the data included in these chapters III, IV and V. Small parts of Chapter VII, Geologic History, having to do with the Kansan (pages 438 to 440), and of Chapter VIII, Summary and Conclusions, having to do with the Kansan (page 443) and the associated gravels (pages 444 to 445), should also be revised to accord with the new interpretation. The chapters on the Wisconsin and the Nebraskan in the report of 1917 need no revision. The relation of this Iowan drift region of northwestern Iowa to the other drift regions

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

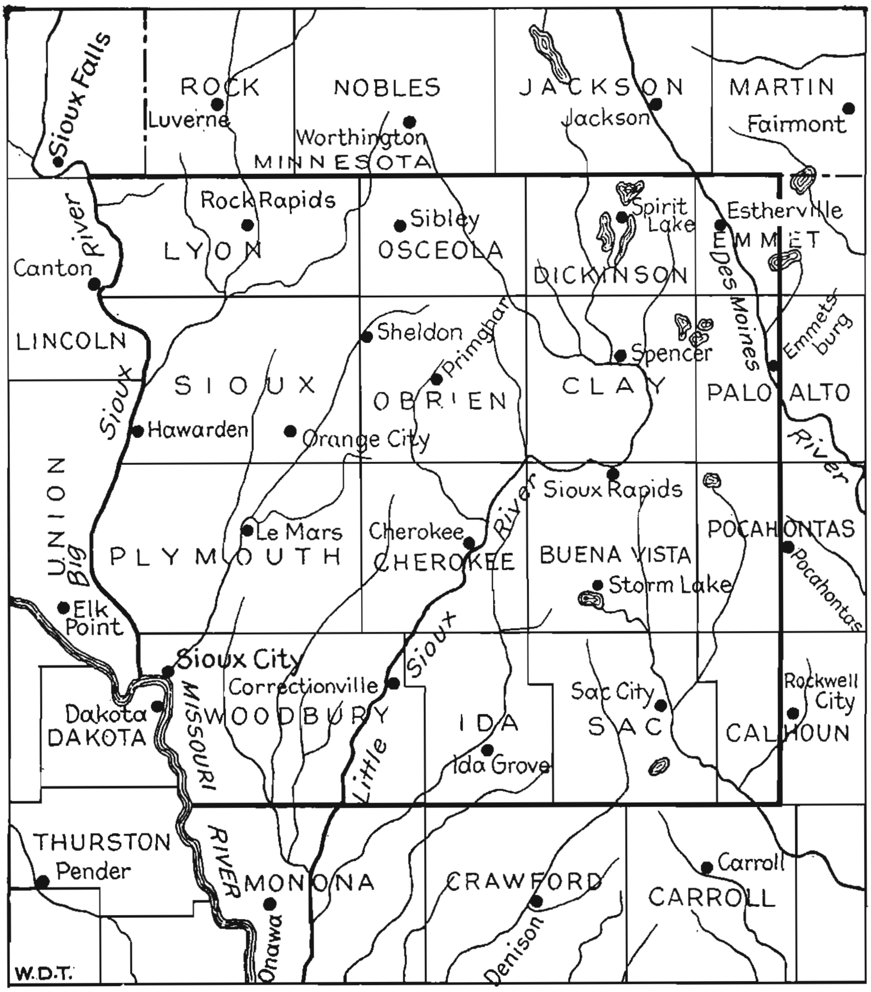

FIG. 1.—Outline map of northwestern Iowa showing counties and principal towns. The area treated in this report is enclosed within the heavy lines.

of the Mississippi valley is shown in figure 2, which has been published by Kay.

In the present report Chapter I summarizes that part of the earlier work in northwestern Iowa which bears directly on the area here called Iowan. Chapter II treats the Iowan drift region including certain associated gravels. Chapter III treats the Kansan drift region. Chapter IV deals with the loess and Chapter V with the gravels in the valleys chiefly of the Iowan drift region. The report closes with a summary of the conclusions reached concerning the various subjects treated in the report.

In the discussion of several subjects the material of a more detailed character is placed in smaller type and may be omitted by the general reader without losing the continuity of the discussion.

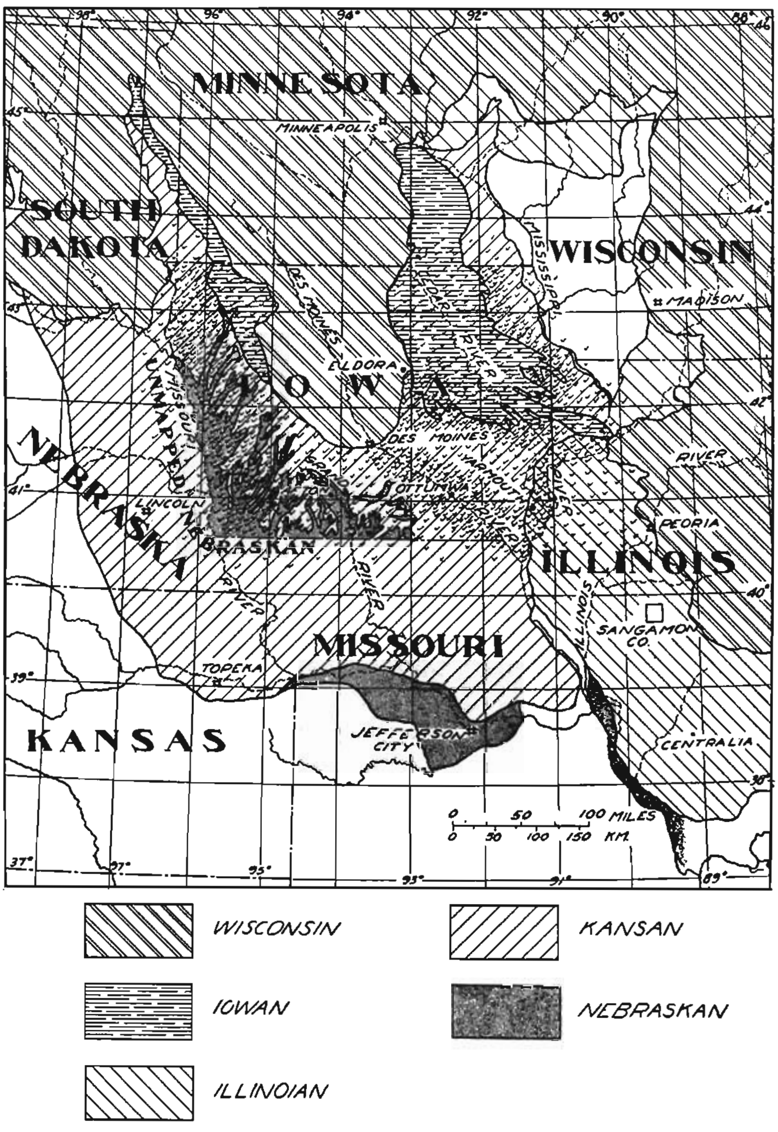

FIG. 2.—Pleistocene map of the Mississippi valley showing the relation of the Iowan drift region of northwestern Iowa (horizontal broken lines) to the other drift regions. (Kay, Am. Jour. Sci., vol. XXI, p. 159, fig. 1.)

CHAPTER I

SUMMARY OF EARLIER WORK

Work Preceding 1909

The summary which follows does not attempt to review all the geologic work in northwestern Iowa or even all the work on the Pleistocene but emphasizes particularly those writings which bear in some way on the question of the age of the drift of that part of northwestern Iowa west of the Wisconsin boundary. These writings were briefly noted as a part of Chapter I of the 1917 report but because of their bearing on the primary problem of the present report they are here discussed much more fully.

Chamberlin in Geikie's Great Ice Age.—The first assignment of some part of northwestern Iowa to a drift sheet younger than the Kansan and older than the Wisconsin was made by Dr. T. C. Chamberlin in his chapter on North America in James Geikie's "The Great Ice Age" (1894). Plate XV of that work shows an area of Iowan drift 25 to 30 miles wide west of the Des Moines lobe in northwestern Iowa, including most of the second tier of counties east of Big Sioux and Missouri rivers. To the west of this belt he mapped Kansan drift.

Preliminary Work by Bain, 1896.—The first suggested assignment of this character in the reports of the Iowa Geological Survey is in Volume VII (1897), in the administrative report of Doctor Calvin for 1896. On page 18, in narrating the glacial stages affecting Iowa, he wrote: "Fourth Glacial Stage, Iowan. During this stage the northern half of Iowa was overrun by glaciers. The southern limit of this incursion may be traced a few miles north of a line drawn from Iowa City to Des Moines, and then deflected northwestwardly to Plymouth county." On page 20, he wrote: "Prof. R. D. Salisbury, ... accompanied Mr. Bain upon a short trip across the northern portion of the state, going as far west as Sioux City and Rock Rapids. The topographic characteristics of the Wisconsin and Iowan were studied and the probable equivalence of the drift sheets east and west of the Des Moines lobe was tentatively decided upon. The correlation forms a good basis for next season's work,".

Volume VI of the Iowa Geological Survey bears the publication date of 1897, as does Volume VII, but the date of the letter of transmittal is December 31, 1897, one year later than that of Volume VII. Volume VI apparently came out later for it contains footnote references to Volume VII. In this Volume VI is a paper by H. F. Bain entitled "Relations of the Wisconsin and Kansan Drift Sheets in Central Iowa". On page 462 he wrote: "There is in the northwestern portion of the state a drift which in physical constitution and topographic development resembles the Iowan of eastern Iowa, and it has been provisionally correlated with that formation." For this provisional correlation he refers to Plate XV of Geikie's Great Ice Age and the statement of Calvin on page 20 of Volume VII of the Iowa Geological Survey as quoted in the preceding paragraph.

On a "Preliminary Outline Map of the Drift Sheets of Iowa" forming Plate XXVIII, opposite page 467 of this report by Bain, northwestern Iowa west of the Wisconsin boundary is set off on the south by a line labeled "Probable Limit of Iowan Drift". This line leaves Big Sioux river in southwestern Plymouth county and runs eastward across the south part of this county, the southwest corner of Cherokee county, the northeast corner of Ida county, and the northwest corner of Sac county, to the Wisconsin boundary in northern Sac county. This probable Iowan area of northwestern Iowa included all of Lyon, Osceola, Sioux and O'Brien counties, the northern four-fifths of Plymouth county, practically all of Cherokee county, the western parts of Dickinson, Clay and Buena Vista counties, and small areas in northeastern Ida and northwestern Sac counties.

Bain's Work in Plymouth County, 1897.—Volume VIII (1898) of the Iowa Geological Survey contains a report on the geology of Plymouth county by H. F. Bain. He spoke of this as "a report on the first area studied by the Survey with especial reference to the drift problems of northwestern Iowa" (page 319). He emphasized the freshness of the till below the loess, saying that it showed little sign of leaching or oxidation and had no ferretto zone. The age of the till was discussed rather fully (pages 341 to 351), the following four possibilities being considered: (1) Kansan, (2) Illinoian, (3) Iowan, (4) Extra-morainic Wisconsin. These possibilities were presented from the viewpoints of topographic development, physical character, alteration, and stratigraphic relationship, and it was found that some viewpoints favored one interpretation, some another. In conclusion he wrote (page 350): "The balance of evidence would seem to indicate that the drift is either Illinoian or Iowan, and since it has already been provisionally referred to the latter it may for the present rest in that category. Clearly it is not Kansan, and while certain elusive evidence not yet well enough in hand to discuss, seems at times to link it with the Wisconsin, the bulk of the phenomena seems to indicate an earlier age."

In the Administrative Report of the Assistant State Geologist in this same Volume VIII Bain listed as one of the results of his work in northwestern Iowa "the approximate determination of the southern limits of the Iowan (?) drift sheet in the region" (page 27) and noted the presence of Iowan (1) at several places near Rock Rapids in Lyon county, (2) in eastern Sioux county, (3) in Cherokee county, (4) near Storm Lake in Buena Vista county just outside the Wisconsin moraine, (5) near Correctionville and at Sioux City in Woodbury county, (6) at Ida Grove and for some considerable distance south in Ida county, and (7) at Carnarvon in southeastern Sac county. On page 351 in the Plymouth county report he indicated that the boundary between this Iowan (?) of northwestern Iowa and the Kansan farther south was difficult to determine because of the thickness of the loess and the scarcity of exposures, and it could "only be outlined as running from Carroll northwest through the northern tier of townships in Crawford county". This indicated boundary is 20 to 25 miles south of that drawn by Bain a year earlier as shown on Plate XXVIII of Volume VI, and it placed in the Iowan at least the northern part of Woodbury county, which he in his earlier report on this county[2] had called Kansan drift. Bain apparently at this time placed in the Iowan(?) all of northwestern Iowa outside the Wisconsin moraine which had a relatively fresh drift to the surface.

Bain's Work in Carroll County, 1898.—This interpretation, which placed all the fresh drift of northwestern Iowa as far south as central Carroll county in the Iowan, was not borne out by the next season's work, for in the Administrative Report of the Assistant State Geologist in Volume IX, Mr. Bain wrote (page 26): "In Carroll county one of the interesting results of the season's work has been the demonstration that much of the extra-morainic drift, heretofore believed to be young and provisionally correlated with the Iowan, belongs to an anomalous phase of the Kansan. What may be the correct age of

[2] Iowa Geol. Survey, Vol. V, p. 279, 1896.

the extra-morainic drift north and west of Carroll county can not yet be stated."

In this same volume is Bain's report on the Geology of Carroll County[3]. He interpreted all the county outside the Wisconsin as Kansan, recognizing two types of Kansan outcrops. The first is that, typical for the Kansan farther south, which shows ferretto, leaching, rotted bowlders, etc., at the top of the drift. The second is an abnormal type in which these phenomena are lacking and fresh till continues to the top. He found both types in the same region but in general found an increase of the unleached type to the west and the north in the county. Both types were overlain by the loess which was deposited after the erosion of the Kansan region and it was evident that they were but different phases of the same drift. He recognized the fact that the unleached type resembled closely the Kansan drift commonly 5 to 10 feet below the ferretto and interpreted these abnormal exposures as being due to erosion, which had removed the ferretto and leached zone before the loess was deposited. On page 88 he wrote: "No attempt can be made here to fix the age of the extra-morainic and fresh looking drift in the counties to the north. The work of the present field season has shown that the reference of this drift to the Iowan is probably wrong."

Wilder's Work in Lyon and Sioux Counties, 1899.—In Volume X appeared a report by Frank A. Wilder on the geology of Lyon and Sioux counties[4] in the northwest corner of the state next north of Plymouth county, which Bain had tentatively interpreted as Iowan. Wilder noted (page 125) that the drift of northwestern Iowa had never been positively identified with any of the established drift sheets of other parts of the state and that one of the reasons for undertaking at that time the geological study of Lyon and Sioux counties was to obtain, if possible, information that would make such correlation possible. He stated that the drift of these counties was the same as that in Plymouth and Woodbury to the south and that no line of separation had been found between this unleached drift of northwestern Iowa and the typical Kansan of southern Iowa, which continued north to Carroll county, where exposures of the typical southern Iowa Kansan, with ferretto, and of the unleached northwest Iowa till both ex-

[3] Bain, H. F., Geology of Carroll County: Iowa Geol. Survey, Vol. IX, pp. 49-107, 1899.
[4] Wilder, Frank A., Geology of Lyon and Sioux Counties: Iowa Geol. Survey, Vol. X, pp. 81-184, 1900.

isted in the same region.[5] He thought that this lack of alteration and leaching of the northwest Iowa drift might be accounted for by the smaller rainfall of northwestern Iowa as compared with that of southern Iowa and by the nature of the topography.

Wilder noted (page 132) that: "Topographically the drift is, perhaps, more closely related to the Iowan" but if, as commonly held, the loess was related to the Iowan the underlying drift could not be Iowan, since evidently a considerable interval elapsed between the deposition of the drift and the overlying loess. In conclusion he wrote: "Considering everything, it seems safer to consider the loess-covered drift of Lyon and Sioux counties as Kansan until something is found in the way of a southern boundary to distinguish it from the recognized Kansan farther south." (Figure 3.)

Wilder mapped the extreme northeast corner of Lyon county, approximately the northeast half of Elgin township, as "Wisconsin Drift" with patches of "Altamont Moraine" (page 118) and in the text (pages 132 to 138) treated it all under the heading "The Altamont Moraine" stating that all of this area in Lyon county was morainic. He described this region in a very positive way as without a loess covering, and with a fresh drift, yellow in color, only slightly oxidized, invariably unleached. Southwest of the Altamont moraine he mapped (page 118) a belt with an average width of about four miles as "Wisconsin Partially Stratified" and interpreted it as outwash from the Wisconsin.

The first interpretation of northeastern Lyon county as Wisconsin was recorded by Bain in Volume IX published one year earlier than the report by Wilder. In his Administrative Report in this volume Bain commented on a trip through northwestern Iowa and adjacent portions of Minnesota and South Dakota, in company with J. E. Todd and Frank Leverett, and wrote (page 26): "Mr. Leverett traced the morainic hills of the Wisconsin drift into the northeast corner of Lyon county, and it seems probable that other changes in the mapping of the drift sheets of that region will be necessary." Wilder made no reference to this work of Mr. Leverett, but he must have known of it because of the close association of Bain with the work of Wilder in Lyon county.

These interpretations by Wilder were apparently concurred in by Bain, who had previously interpreted differently the drift of Plymouth

[5] Iowa Geol. Survey, Vol. IX, pp. 82-85 and map, p. 106, 1899.

county to the south. In the Administrative Report of the Assistant State Geologist in Volume X, Bain wrote (page 30): "In company

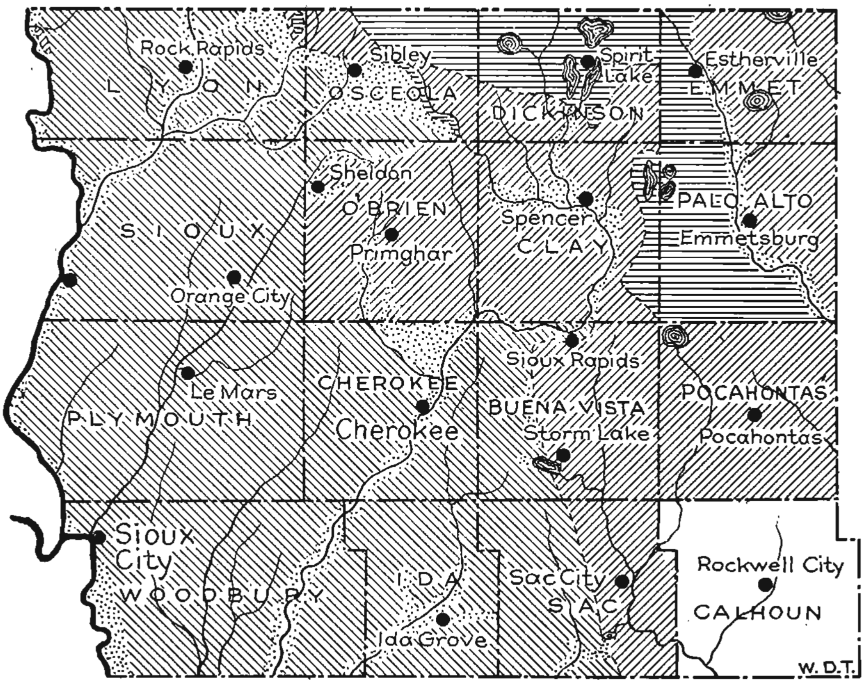

FIG. 3.—A map of northwestern Iowa made by compiling the Pleistocene maps in the county reports.

"Kansan drift" of Woodbury, Ida and Sac counties; "Loess overlying older drift (Kansan)" of Cherokee and Buena Vista counties; "Loess overlying Kansan" of Lyon and Sioux counties; "Loess overlying older drift" of Osceola and O'Brien counties; "Provisionally Iowan" of Plymouth county.

"Wisconsin Drift" of Lyon, Osceola, Dickinson, O'Brien, Palo Alto, Buena Vista, Pocahontas and Sac counties; "Wisconsin Drift Plain" of Clay county; "Wisconsin Plain" of Emmet county.

"Altamont Moraine" of Lyon county; "Wisconsin Moraine" of Osceola county; "Knobby Drift, Morainic" of Dickinson county; "Knobby Drift" of Clay county; "Wisconsin Drift, affected by Morainic Knobs" of Emmet county; "Morainic Deposits" of Palo Alto county.

"Wisconsin Partially Stratified" of Lyon, Sioux, Osceola, Dickinson and Clay counties; "Wisconsin Gravel Train" of O'Brien county; "Wisconsin Overwash Gravels" of Cherokee county; "Alluvial Deposits" of Emmet, Palo Alto, Cherokee, Buena Vista and Sac counties; "Alluvium" of Ida county.

with Mr. Wilder I made a bicycle journey from Carroll county northwest as far as Sioux Falls, studying the drift of the intervening region. Mr. Wilder then took up the problem and his report, appearing in this volume, shows how successfully he has attacked it. I have been over most of the region in his company or alone, and would wish heartily to concur in his findings." In the Administrative Report of the State Geologist, Doctor Calvin wrote (page 15): "Mr. Wilder has also shed much light upon the vexed question of the age of the drift of the northwestern part of the state. His conclusions, while differing somewhat from those previously held by the Survey, are founded on careful study and seem worthy of every confidence. Probably a final opinion on the subject can not be rendered until more of the region shall have been investigated."

Macbride's Work in Osceola and Dickinson Counties, 1899.—In the same volume with Wilder's report on Lyon and Sioux counties is a report by Professor Macbride on the Geology of Osceola and Dickinson Counties[6], which lie next east of Lyon county along the state line. Macbride continued the mapping units used by Wilder in Lyon county eastward into Osceola county (figure 3). The northwest part of Osceola county adjoining Wilder's "Wisconsin Drift" of northeastern Lyon county, the southeast part of Osceola county, and the southern third of Dickinson county were mapped as "Wisconsin Drift" outside the distinctly knobby area to the north which was mapped as "Wisconsin Moraine". The area of "Wisconsin Partially Stratified" which was continued from Lyon county with a width of two miles on the county line was mapped as broadening out in the central part of Osceola county to an area six to eight miles across and thence narrowing again to two to three miles where it strikes the south boundary of the county west of Ocheyedan river. The southwest corner of Osceola county was mapped as "Loess, overlying older drift" and provisionally referred to the Kansan (page 218).

Macbride's Work in Clay and O'Brien Counties, 1900.—In Volume XI, one year later, Professor Macbride reported on Clay and O'Brien counties.[7] The eastern edge of Clay county was mapped as "Knobby Drift", terminal moraine of Wisconsin age (figure 3). All the rest of Clay county and all of O'Brien county, except the northwest corner, were mapped as "Wisconsin Drift". A narrow wedge-shaped area in the northwest corner of O'Brien county, 18 miles long from east to west and only 5½ miles wide at the west line, was mapped as "Loess, overlying older drift (Kansan)", apparently to match up with the similar area of southwestern Osceola county as mapped the previous year. The unit of "Wisconsin Partially Stratified" used by

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[6] Macbride, T. H., Geology of Osceola and Dickinson Counties: Iowa Geol. Survey, Vol. X, pp. 185-239, 1900.

[7] Macbride, T. H., Geology of Clay and O'Brien Counties: Iowa Geol. Survey, Vol. XI, pp. 461-508, 1901.

Wilder in Lyon county and continued by Macbride across Osceola county to the O'Brien county line was not used in the mapping of O'Brien county. The "Wisconsin Drift" of the O'Brien county map joins along the west line of the county with the "Kansan Drift" of the earlier Sioux county map of Wilder (figure 3), but no discussion of the lack of agreement or what caused the change of opinion concerning this region was given.

This mapping of Macbride in Clay and O'Brien counties created a large area of "Wisconsin Drift" in northwestern Iowa lying outside the Wisconsin moraine, an extra-morainic Wisconsin drift. In Volume XI there was published as Plate II a "Preliminary Outline Map of the Drift Sheets of Iowa," and, in accord with this work of Macbride, a considerable area in northwestern Iowa, including most of O'Brien and Clay counties and parts of Osceola, Dickinson, Cherokee and Buena Vista counties, was shown as "Wisconsin" but lying outside of the "Wisconsin Moraine."

Macbride's Work in Cherokee and Buena Vista Counties, 1901.— Subsequent work to the south evidently did not bear out this conclusion concerning the extra-morainic Wisconsin area, for in his report on Cherokee and Buena Vista counties,[8] which appeared one year later in Volume XII, Professor Macbride mapped Cherokee county, which lies south of O'Brien, and the west half of Buena Vista county, next south of Clay county, as "Loess, overlying older drift (Kansan)". This abuts on the north at the county lines against the extra-morainic "Wisconsin Drift" area of O'Brien and Clay counties, as is shown in figure 3. The central and east parts of Buena Vista county were mapped as "Wisconsin Drift" but without a morainic belt along the boundary.

The previous assignment of the drift of O'Brien and Clay counties to the Wisconsin was questioned (page 319), with the suggestion that it might prove to be Early Wisconsin or even older. The problem was evidently considered the same as that in Plymouth county, to which report the reader was referred for a fuller presentation of the problem. In the Plymouth county report the drift had been provisionally referred to the Iowan.[9]

A second "Preliminary Outline Map of the Drift Sheets of Iowa"

[8] Macbride, T. H., Geology of Cherokee and Buena Vista Counties: Iowa Geol. Survey, Vol. XII, pp. 303-353, 1902.
[9] Iowa Geol. Survey, Vol. VIII, pp. 341-351, 1898.

appeared in 1904 in Volume XIV.[10] Like the earlier map[11] it shows an area of "Wisconsin" west of the "Wisconsin Moraine," but the west boundary of this area is five to ten miles farther east in O'Brien, Cherokee and Buena Vista counties. The area includes most of Clay, Osceola and O'Brien counties and smaller parts of Dickinson, Buena Vista, Cherokee and Lyon counties. A very similar map was published in 1905 in Bulletin 2 of the Iowa Geological Survey, but on this map the Wisconsin Moraine was not shown and the "Wisconsin Drift" area continued unbroken westward to the west boundary of the extra-morainic Wisconsin of the other map.

Macbride's Work in Sac and Ida Counties.—In Volume XVI Professor Macbride reported on Ida and Sac counties,[12] which lie to the south of Cherokee and Buena Vista counties. He showed the Wisconsin boundary extending north-south across Sac county and connecting up with the earlier tracing in Buena Vista county to the north and Carroll county to the south. The west half of Sac county and all of Ida county were mapped as Kansan drift (figure 3).

The work in Sac and Ida counties completed the county report work on that part of northwestern Iowa with which we are concerned. There is considerable lack of agreement between certain of the county maps and some contradictions in the texts. This lack of agreement is shown on figure 3, which was made by compiling the Pleistocene maps of the county reports. New interpretations were adopted in some cases without showing that the earlier ones were no longer tenable. In some cases divisions were placed upon maps without discussion, and boundaries were mapped without being traced in the text and without discussion of the characters upon which the boundaries were based. This makes it difficult to determine just what the final opinion was on certain points. Thus the matter stood when the writer began his studies in northwestern Iowa in 1909.

Work of the Writer from 1909 to 1916

The work of the writer in northwestern Iowa began in 1909 with the problem of retracing the Wisconsin drift boundary on the west side of the Des Moines lobe north of Carroll county.[13] This retracing left

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[10] Iowa Geol. Survey, Vol. XIV, Pl. III, 1904.
[11] Iowa Geol. Survey, Vol. XI, Pl. II, 1901.
[12] Macbride, T. H., Geology of Sac and Ida Counties: Iowa Geol. Survey, Vol. XVI, pp. 509-562, 1906.
[13] Iowa Geol. Survey, Vol. XXVI, pp. 251-320, 1917.

outside the Wisconsin boundary that questionable area which had been variously interpreted by earlier writers as Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan, or Kansan. This questionable area was studied during parts of the field seasons of 1910 and 1911. Various lines of evidence, chiefly topographic, suggested that the eastern part of this area should be assigned to a separate drift region intermediate between the Kansan on the west and the Wisconsin on the east. However, a super-Kansan drift sheet could not be generally separated and the topography did not seem to afford a consistent boundary line. Further, it was recognized that this questionable area corresponded most nearly to the Iowan of northeastern Iowa, and the identity of the Iowan was at that time very strongly questioned by most geologists outside of Iowa and probably by some within the state. It appeared, therefore, that to attempt to establish a post-Kansan pre-Wisconsin drift region in northwestern Iowa would be to create another Iowan problem. The conclusion was reached that all of northwestern Iowa west of the Wisconsin boundary was of Kansan age and a report was prepared by the writer with this interpretation.

It was on the basis of this conclusion that the "Map of Iowa Showing Drift Sheets," published as Plate LXV of Volume XXIV (1913) of the Iowa Geological Survey, was prepared. This map shows the Kansan drift over all of northwestern Iowa west of the Wisconsin boundary, as traced in the work of 1909. This map was reproduced as Plate XIV of Volume XXVI (1917).

During the summer of 1912 Mr. Frank Leverett of the United States Geological Survey, working in southwestern Minnesota, recognized a drift region between the Wisconsin and Kansan and traced it southward to the Minnesota-Iowa line. This corresponded to the division south of the state line which had been tentatively considered by the writer in 1910 and 1911 as intermediate in age between the Wisconsin and Kansan. Mr. Leverett found this division very distinct in Minnesota and bordered by a moraine which he traced from Watertown, South Dakota, through southwestern Minnesota to the Iowa line.[14]

In 1913 the writer re-examined this intermediate area in northwestern Iowa and compared it with Leverett's area in southern Nobles county north of the state line. It was found that the characters of Leverett's area continued into Iowa with decreased distinctness and that a

[14] Letter from Mr. Leverett to the writer in December, 1912.

very indefinite boundary could be traced southward across eastern Lyon, northeastern Sioux, southwestern O'Brien, eastern Cherokee, northeastern Ida and southwestern Sac counties to the point where it passed beneath the Wisconsin boundary. It was then decided to make this the continuation in Iowa of Leverett's area. In Iowa the recognition of this intermediate area rested almost entirely on topography.

The writer then revised his report on northwestern Iowa on the basis of the existence of a drift sheet intermediate in age between the Kansan and the Wisconsin. In the manuscript this region was called Iowan with a chapter entitled "The Iowan Drift Region." The reasons for using the term Iowan were given but with the qualifying statement "a positive correlation has not as yet been made with the Iowan drift region of eastern Iowa."

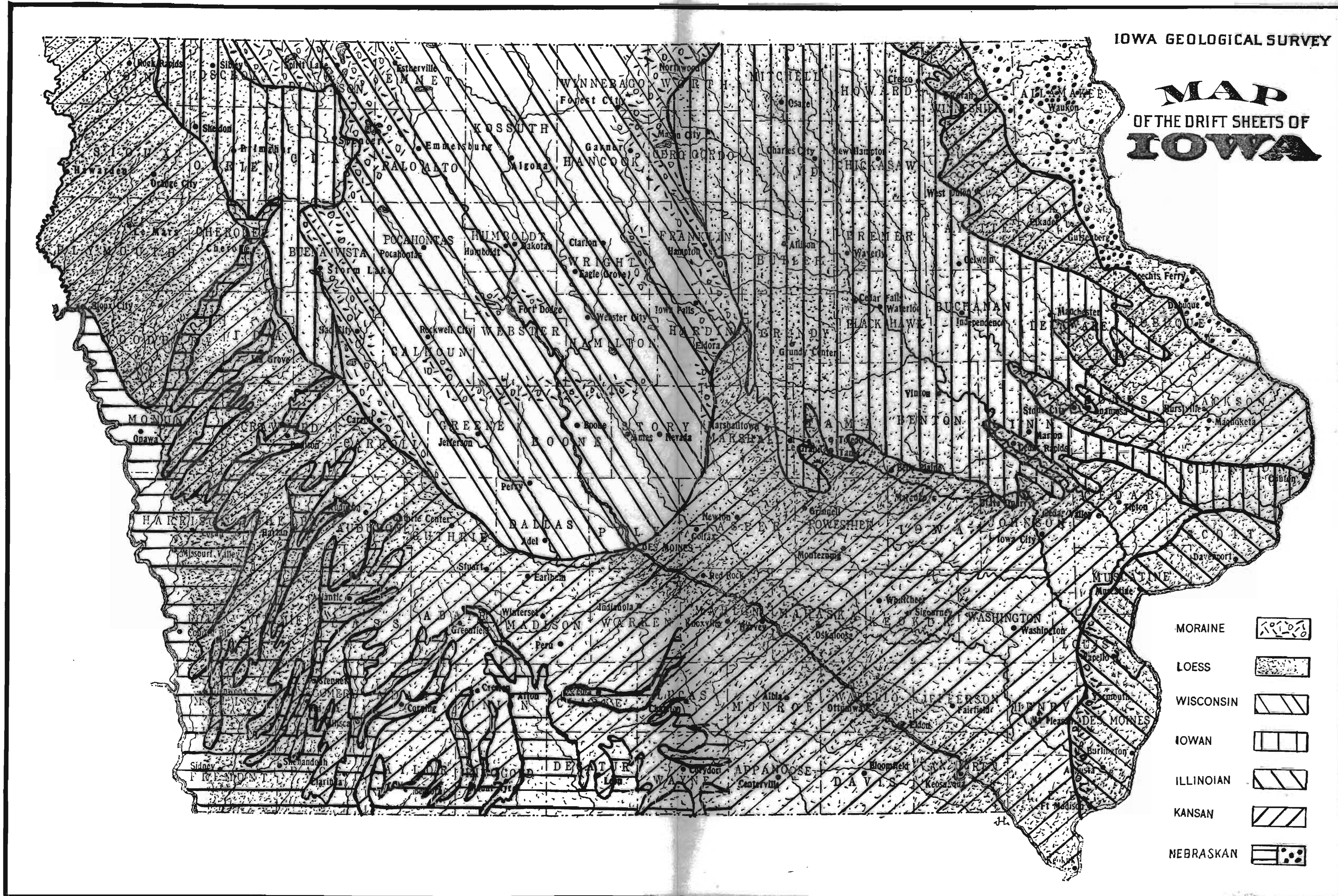
Although the writer then agreed with Mr. Leverett in the recognition of this intermediate drift region, they did not agree as to its age. The writer believed that a loesslike clay which exists over the intermediate drift region was the equivalent of and the continuation of the Missouri river loess, which it was generally agreed was the equivalent of the Peorian loess of eastern Iowa and, therefore, that the intermediate drift region must be Iowan or older. Mr. Leverett, on the other hand, believed, in 1913, that this intermediate region was Wisconsin and so published concerning it in 1919.[15]

The manuscript on northwestern Iowa recognizing the Iowan drift region was submitted to the Director of the Iowa Geological Survey in May, 1915, but because of the lack of agreement noted above as to the correlation of the intermediate drift region the publication of the report was deferred from time to time.

In 1916, the writer, in company with the Director of the Iowa Survey, Doctor Kay, returned to northwestern Iowa to attempt to solve the question of the age of the intermediate drift area. A more detailed study of the loesslike clay that overlies the intermediate drift area confirmed the earlier opinion of the writer and convinced Doctor Kay that this loesslike clay is the continuation of, and the equivalent of, the loess of the Kansan region, which was generally considered to be Peorian. It was, therefore, impossible to agree with Mr. Leverett that this intermediate drift region was Early Wisconsin in age.

The writer had always questioned somewhat the identity of the intermediate area as a distinct drift region, and after showing in 1916

[15] Minnesota Geol. Survey, Bull. 14, pp. 51-52, and map in pocket, 1919.


IOWA GEOLOGICAL SURVEY
MAP
OF THE DRIFT SHEETS OF
IOWA
MORAINE
LOESS
WISCONSIN
IOWAN
ILLINOIAN
KANSAN
NEBRASKAN

that it must be preloess in age he again reviewed the bases for its recognition. In view of the fact that there was no generally recognizable super-Kansan drift sheet, and that the boundary between the Kansan and the supposed intermediate area was in general indefinite and questionable, the writer returned, at the end of the field season of 1916, to the conclusion which he held in 1911, that all of northwestern Iowa west of the Wisconsin boundary belonged to the Kansan drift region.

On the basis of this interpretation the manuscript was again revised and this time published as "The Pleistocene Geology of Northwestern Iowa."[16] There are many parts of this report of 1917 that might be reviewed here, but the more important conclusions bearing on the subjects with which we are concerned in the present report may be shown by a few quotations from the section entitled "Summary and Conclusions" (pages 442-445).

"*Kansan Drift.*—All of northwestern Iowa west of the Wisconsin drift boundary is assigned to the Kansan drift region on the basis of the identity of the till and the presence of a mantle of loess over the entire region. The absence of leached Kansan till in northwestern Iowa is explained by the removal of this leached zone by erosion of the entire region below the original level at which leached till may have formed.

"*Gravel Bowlders and Gravel Hills.*—The gravel and sand masses included in the till are parts of frozen gravel deposits which were plowed up by the advancing ice sheet. As is shown by the composition of the gravel, by the freshness of the material and by the clay-balls, most of these masses are of the same age as the inclosing till. They represent deposits made in front of the advancing ice sheet, which a little later plowed them up.

"The gravel hills of the Kansan drift region are included gravel bowlders which have been exposed at the surface by the removal of the inclosing till. They come to stand above the surface of the till by the relatively greater resistance to erosion of the porous gravel mass.

"*The Valley Gravels.*—The valley gravels occupy valleys cut into the Kansan drift. The material for these deposits was released by erosion from the Kansan drift and was accumulated in the valleys during a period of time subsequent to the major erosion of the Kansan drift plain and preceding the deposition of the loess."

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

Work Published Since 1916

In Volume XXVI of the Iowa Geological Survey there appeared a report by Alden and Leighton entitled "The Iowan Drift; A Review of the Evidence of the Iowan Stage of Glaciation".[17] In this report the authors reaffirmed the existence of a post-Kansan pre-Wisconsin drift sheet in northeastern Iowa and stated that it is younger than the Illinoian and older than the Wisconsin. This essentially reaffirmed the opinion of Doctor Calvin concerning the Iowan drift region and in the opinion of most geologists re-established the Iowan as one of the independent stages of Pleistocene glaciation. It may be well to note here the bearing of this conclusion on the work in northwestern Iowa. During the progress of the work there the Iowan of northeastern Iowa was under severe question and to postulate an intermediate drift region in northwestern Iowa on questionable evidence seemed doubly questionable, for it appeared that it would have to stand without the support of the type, northeast Iowa region. Now, with the type region reaffirmed, it would be much easier to put another questionable area, as that in northwestern Iowa, with it.

In 1919 there appeared a report by Leverett and Sardeson entitled "Surface Formations and Agricultural Conditions of the South Half of Minnesota."[18] On the map which accompanies the report there is in southwestern Minnesota an area about 10 miles wide, lying to the southwest of the morainic belt of unquestioned Wisconsin age. At the state line this is the continuation of the intermediate drift region of northwestern Iowa. This belt is mapped as "Till or boulder plains, clayey," a unit which includes also all the Wisconsin ground moraine farther northeast. In discussing southwestern Minnesota they wrote (pages 51-52): "there is a thin sheet of relatively young gray drift, forming a veneer over the eroded surface of the old gray drift, which lies outside the well defined moraine of Wisconsin drift. . . . In the opinion of the present writers, the drift which veneers the eroded district outside of the moraine is not markedly older than that of the moraine of Upham interpreted to be the outer limits of the younger drift, and should, therefore, be included with it." This statement just quoted showed plainly the opinion of Leverett and Sardeson that the "intermediate" area was of Wisconsin age.

In 1922, Leverett, in a paper entitled "Glacial Formations of the

[17] Alden, W. C., and Leighton, M. M., Iowa Geol. Survey, Vol. XXVI, pp. 49-212, 1917.
[18] Leverett, Frank, and Sardeson, Frederick W., Minnesota Geol. Survey, Bull. 14, 1919.

Coteau des Prairies,"[19] wrote, "A drift of debatable age, but apparently somewhat older than the Wisconsin drift, and referred provisionally to the Iowan stage of glaciation, extends a few miles beyond the undoubted Wisconsin drift in South Dakota, Minnesota, and Iowa and covers the Missouri-Mississippi divide nearly half way across Iowa." On the accompanying map (page 103) Leverett labeled this area "Iowan(?) Drift". This area in Minnesota is the one which Leverett and Sardeson called Wisconsin outside the moraine in 1919 and in northwestern Iowa it is the intermediate drift region mapped by the writer in 1913 and called Iowan in the unpublished manuscript of 1915. Leverett had now abandoned, or at least questioned, the Wisconsin age of this area.

Further Studies in Northwestern Iowa

In the summer of 1925 Doctor Kay was on a trip in northwestern Iowa with Doctors Leverett, MacClintock and Apfel when they found an exposure near Sheldon, in northwestern O'Brien county, which appeared to offer very strong evidence in support of an intermediate drift sheet. This section has been published by Doctor Kay and will be given on a later page of the present report (page 51).

As a result of this trip in northwestern Iowa, and chiefly as a result of finding the section noted above, Doctor Kay asked the writer to return to northwestern Iowa for a field conference with him and for such additional field work as the problem deserved. It was not possible to find a time suitable to both Doctor Kay and the writer until the field season of 1927.

In the latter part of June, 1927, the writer joined Doctor Kay at Iowa City for this study. They began by a trip over the Iowan of northeastern Iowa, which the writer had never studied. They then spent about two weeks in a review of the evidence for an intermediate drift region in northwestern Iowa. Very few new exposures of any consequence were found, but a number of the exposures studied by the writer in the years between 1910 and 1916 were re-examined in the light of the reaffirmed Iowan of northeastern Iowa and the new interpretations of Doctor Kay concerning the Loveland deposits of western Iowa. As a result of this study it was decided that the evidence was sufficient to justify an interpretation of an intermediate drift region as used in the unpublished manuscript of 1915.

[19] Bull. Geol. Soc. of America, Vol. 33, pp. 101 and 103, 1922.

It is necessary, therefore, that Chapters III, IV, and V of the report of 1917[20] dealing with the Kansan drift and associated gravels be replaced by chapters dealing with the Kansan drift, Iowan drift and the associated gravels. The present report is, therefore, in large part from the unpublished manuscript of 1915, which recognized an Iowan drift region in northwestern Iowa, modified to include such additional evidence as was obtained in 1916 and in 1927.

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

CHAPTER II

THE IOWAN DRIFT REGION

The region discussed in this chapter is a post-Kansan, pre-Wisconsin drift region lying to the west of the Des Moines lobe of the Wisconsin drift sheet. It includes most of that questionable area of northwestern Iowa which has been variously interpreted as covered with Wisconsin, extra-morainic Wisconsin, Early Wisconsin, Iowan, or Kansan drift.

The extent of this Iowan drift area in northwestern Iowa is shown on Plate I. It covers the major parts of Osceola, O'Brien and Clay counties, considerable parts of Cherokee, Buena Vista and Sac counties, and smaller parts of Lyon, Dickinson, Sioux and Ida counties. Its total area in Iowa is about 2,000 square miles and its eastern limit is the margin of the Wisconsin drift as traced in the report of 1917.[21] Its western boundary, to be traced in detail in this chapter (pages 59 to 84), crosses eastern Lyon, northeastern Sioux, southwestern O'Brien, eastern Cherokee, northeastern Ida and southwestern Sac counties, and near the south line of Sac county is overlapped by the Wisconsin drift. The relation of this Iowan region in northwestern Iowa to the drift sheets of Iowa is shown on Plate II. The entire area of this drift region west of the Des Moines lobe is an elongate area extending from Watertown, South Dakota, across southwestern Minnesota and northwestern Iowa to the south border of Sac county, a distance of more than 200 miles. Through Minnesota its width is 10 to 20 miles. South of the state line the belt widens, because of the eastward swing of the Wisconsin boundary, to 45 miles in O'Brien and Clay counties. It narrows again to 15 miles in northern Cherokee and Buena Vista counties and terminates at the south line of Sac county (figure 2).

CORRELATION

This intermediate drift region of northwestern Iowa is here correlated with the Iowan drift region of northeastern Iowa. A brief statement of the bases for this correlation is given here, but the evidence for the conclusion appears under several headings of this report.

[21] Iowa Geol. Survey, Vol. XXVI, pp. 252-293, 1917.

This intermediate region is younger than the Kansan region to the west and older than the Wisconsin region to the east with its distinctly glacial topography. In contrast with the Wisconsin, undrained depressions and other pronounced glacial features are absent. However, the area has not suffered much erosion and some of its features are constructional.

The position of this intermediate drift region to the west of the Wisconsin drift area of north-central Iowa is comparable to the position of the Iowan drift region to the east of the Wisconsin drift area. The two Iowan areas of northeastern and northwestern Iowa together outline the limits of a lobe of ice which covered most of northern Iowa (Plate II). The general features of the topographies of the two regions are the same and the drift of each cannot, in many cases, be positively distinguished from the Kansan drift below. The Iowan area of northwestern Iowa is overlain, without evidence of elapsed time, by a thin mantle of loess or loesslike clay which, as shown in Chapter IV (pages 116 to 136), is the time equivalent of the Missouri river loess, which is commonly correlated with the Peorian loess of eastern Iowa, which was deposited soon after the Iowan ice epoch.

The history of the assignment of the intermediate region of northwestern Iowa in the Pleistocene time scale was traced in the review of the literature in Chapter I. The more recent correlations are: in 1919 Leverett and Sardeson placed the corresponding area in Minnesota in the Wisconsin,[22] and in 1922 Leverett placed the area provisionally in the Iowan.[23]

TOPOGRAPHY

General Characteristics

The characteristics which distinguish the Iowan drift topography are faint and rather indefinite, and until they are well understood and their significance appreciated, this drift region may easily escape recognition. In order to appreciate and recognize the differences between the Iowan and Kansan drift topographies, one must stay with the work for some time, must go back and forth across the boundary from one drift region to the other, and must compare every minute detail. He who expects to see pronounced differences will be disappointed, and he who attempts to verify or disprove must beware of a hasty judgment.

The entire surface of the Iowan drift is in slopes, mostly definite,

[22] Minnesota Geol. Survey, Bull. 14, pp. 51-52, and map in pocket, 1919.
[23] Bull. Geol. Soc. of America, Vol. 33, pp. 101 and 103, 1922.

but in some cases so gentle as to be almost imperceptible. The entire surface is therefore drained, although in some places poorly so. The undrained depressions which characterize the Wisconsin drift plain are entirely absent from the Iowan drift, but along some of the stream courses on the upland there are marshy areas, and in several places the Iowan plain is so flat as to be poorly drained.

The topography of the Iowan drift presents considerable diversity, ranging from level plains with a relief of only 10 to 20 feet in half a mile to rolling regions with a relief of 40 to 60 feet, and along the larger valleys there are some sharply dissected, rugged areas. The more level areas are chiefly on the great watershed and along the divides between the larger streams in Clay, O'Brien and Osceola counties. Along the larger streams, even in the northern counties, the topography has a moderate relief, and these areas broaden southward at the expense of the slightly rolling interstream areas until the whole is distinctly rolling.

The drainage pattern of the Iowan region is roughly dendritic, and the valleys are relatively broad and straight. A general view from one of the divides where the relief is 20 to 40 feet appears at first to be across an erosional topography, for on either side there may be broad depressions, possibly one to three miles across, and the divides beyond rise essentially to the altitude of the one on which the observer stands. A closer study shows, however, that the slopes are not long, smooth slopes due to erosion but are somewhat uneven and billowy, and the valleys are more or less obstructed. A view across a Kansan drainage basin shows definite locations for the main streams and tributaries, because the slopes are all smooth and the valleys flaring. A view across an Iowan drainage basin does not show the same definiteness of stream courses or smoothness of valley slopes.

It is believed that before the deposition of the Iowan drift this region had an erosional topography developed on the Kansan drift plain, but that along the great divide of the state there were considerable areas that were nearly level as well as more rolling areas farther from the divide. These pre-Iowan features were not completely obliterated by the Iowan drift sheet and still remain as the greater relief features of the region. Upon these larger features the Iowan drift sheet superposed a glacial topography with minor constructional features making uneven billowy slopes.

Description of the Topography

Slightly Rolling Areas.—Most of Osceola county outside the Wisconsin drift boundary is slightly rolling, and the same is true of northern O'Brien county and of western Clay county within the loop of Little Sioux river. On the broader of the interstream spaces some areas are almost level, with a relief of only five to ten feet. A view of one of these level areas in northeastern O'Brien county is shown in figure 4. The largest of these areas is in western Clay county, in Lincoln, Clay and Lone Tree townships, between Willow creek and Ocheyedan river. The surface is so level that the natural drainage is poor, but there is sufficient slope for successful tiling and this is now a very productive farming region. Most of western Clay county within the Ocheyedan-Little Sioux loop has a slightly rolling topography and at many places this comes out to the very edge of the valley, and with its gentle slopes is in decided contrast with the deep, narrow valley of the Little Sioux.

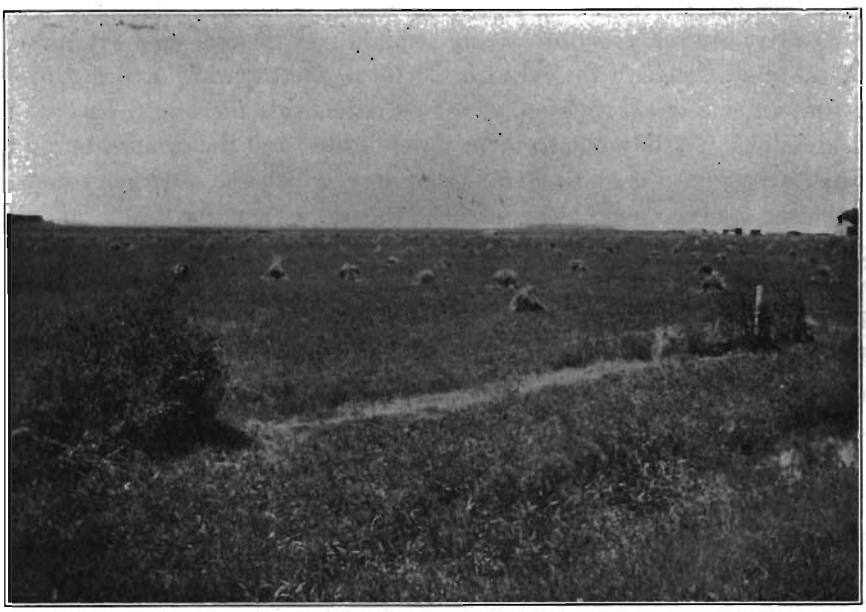

FIG. 4.—View across a level area of the Iowan drift plain northwest of Hartley in northeastern O'Brien county. (Photo by Lees.)

Another quite level area of considerable size is found along the Osceola-O'Brien county line between Melvin and Plessis, and smaller areas exist in north-central Goewey, southeastern East Holman and south-central West Holman townships of Osceola county, and in the southwest half of Lincoln township, O'Brien county. From the large area of slightly rolling topography of northern O'Brien county narrowing areas extend southward along the divides between the Floyd river and Mill creek valleys and between the valleys of Mill and Waterman creeks.

A very level area lies just south of the Wisconsin drift boundary of southwestern Dickinson and southeastern Osceola counties, and similar though smaller areas exist east of Little Sioux river from Milford to Dickens and to Gillett Grove. The evenness of some of these areas may have been accentuated by the outwash from the Wisconsin ice front, but they apparently were level before the Wisconsin epoch.

North of Spencer in the adjoining corners of Sioux, Meadow and Summit townships is probably the flattest area of the Iowan drift plain. It is but little above the Little Sioux valley to the southwest, and is so level as to be poorly drained. The poor drainage of this district is due partly to a low ridgelike belt of sand hills along the edge of the Little Sioux flat which has obstructed the drainage from the north (page 47).

Moderately Rolling Areas.—Within the slightly rolling areas of Osceola, O'Brien and Clay counties there are more strongly rolling belts along most of the larger valleys. These broaden southward along the valleys until the intervening, slightly rolling areas are entirely eliminated. Along some of the valleys, as the Little Sioux below Gillett Grove, and the Waterman, a sharply dissected topography exists.

Most of the more rolling topography lies along the valleys, but there are some areas on the upland entirely surrounded by the slightly rolling topography. Such areas are found in north Goewey and Gilman townships of Osceola county and along the headwaters of Floyd river on the county line northeast of Sheldon. Another area lies between the Little Ocheyedan and the Ocheyedan valleys in southeastern Osceola county and is continued as a narrow belt southward along the west side of the Ocheyedan and Little Sioux valleys.

The Iowan drift region of eastern Cherokee, western Buena Vista, western Sac and northeastern Ida counties is, in general, moderately rolling but includes small patches of but slightly rolling topography. The general relief is 30 to 50 feet and the region is well drained. It is an erosional topography mantled by a thin sheet of Iowan drift.

Erosional Topography along Valleys.—Along some of the larger valleys of the Iowan drift region there are areas characterized by sharp dissection and considerable local relief, giving a very rugged topography along the valleys, although the inter-stream areas present rounded slopes and slight relief. This topography is found along the Little Sioux valley in northeastern Cherokee, southeastern O'Brien, and southern and eastern Clay counties. It exists also along the lower courses of the larger tributaries of the Little Sioux, as Mill, Waterman, Willow and Brooke creeks (figure 5). It has its greatest development in northeastern Cherokee and southeastern O'Brien counties, where Little Sioux river is 175 to 200 feet below the upland, and where many small tributaries have cut three to five miles into the upland, producing a much dissected area with a relief of 125 to 150 feet. The slopes are steep, but the divides are level and project as spurs of the upland between the ravines out to the very edge of the Little Sioux valley.

FIG. 5.—View across a sharply dissected area of the Iowan drift region in the lower course of Brooke creek in northwestern Buena Vista county. (Macbride, Iowa Geological Survey, volume XII, p. 315.)

East of southeastern O'Brien county the sharply dissected belt along the Little Sioux valley is narrower, and at many places the slightly rolling plain comes up to the very edge of the valley. Good examples of this condition exist on either side of the valley in the southwest corner of Clay county, in Gillett Grove township of eastern Clay county, opposite Sioux Rapids and elsewhere. Notably sharply dissected areas are present southeast of Cornell in Herdland township, in section 4 of the same township, in section 27 of Peterson township and at other places.

The area of sharply dissected topography along the Little Sioux valley is more extensive at the mouths of the tributary creeks, and extends up the larger of these creeks for a number of miles. It extends several miles up Willow creek valley in south-central Clay county but with decreasing relief and ruggedness. It continues up Brooke creek valley (figure 5) in northwestern Buena Vista county for about four miles and up other smaller creeks to the northwest of Brooke creek through the north-central part of Brooke township. In southeastern O'Brien county where this sharply dissected topography is so well developed along the Little Sioux, it continues up Waterman creek valley for seven to eight miles through central Grant township. The dissection here is remarkably sharp, giving a topography that is in striking contrast with the level upland to the east and west. The sharply dissected topography extends six to eight miles up Mill creek valley in Cherokee county and affects the lower courses of its tributaries.

If they are viewed from a distance, most of these tributaries of the Little Sioux appear to have broad shallow valleys, but as they are approached more closely what appeared to be broad shallow valleys are found to be trenched by narrow steep-sided valleys (figure 6).

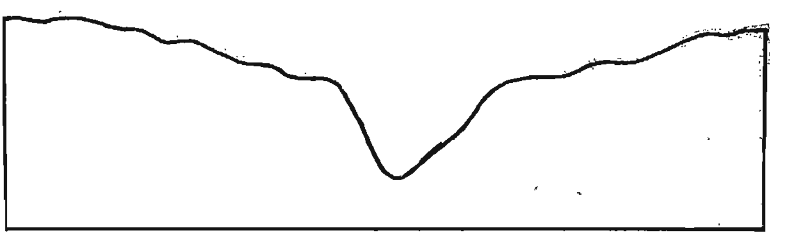

FIG. 6.—Cross profile of a tributary valley of the Little Sioux showing the trenchlike inner valley cut into the broader outer valley.

This feature is particularly prominent in the lower courses of the tributaries. Farther up these creeks the narrow valleys in the bottoms of the older ones grow shallower until they terminate, and above their upper ends the streams flow through broad, shallow valleys similar to the wider parts of the valleys farther down stream. The valley of a small creek which joins Mill creek in section 10 of Cherokee township, and which is followed by the Illinois Central railway northward toward Larrabee, shows well the passage from the sharply dissected topography to topography of the upland type. In its lower course the inner valley is 60 to 75 feet deep, but northward it becomes shallower until at Larabee it terminates, and north of this place the stream flows in a broad, shallow valley characteristic of the Iowan upland.

When the Ocheyedan-upper Little Sioux system was thrown southwestward across the great watershed into its present course,[24] new conditions were established, and the great quantity of water carried by the Little Sioux soon deepened its valley notably and destroyed the adjustment between it and its tributaries. The rejuvenated tributaries and the valleyside gullies then began to carve out the sharply dissected topography described above. This sharp dissection is all the work of post-Wisconsin time, and cutting in the tributary valleys is still in progress.

Aggraded Areas.—At several places within the Iowan region there are almost level areas that have been formed by the filling in of low areas with gravel. A good example is found west of Primghar in central O'Brien county, where several branches of Mill creek unite (page 157). Here a level area several square miles in extent is almost wholly underlain with gravel. Another lies east and southeast of Sibley in East Holman township, Osceola county, where areas extending some distance back from the present valleys are underlain with gravel (page 143).

Gravel Hills.—At various places on the Iowan plain there are gravel hills or mounds hardly distinguishable from the usual features of the region. Some of them are in groups, some are in rows along the upland valleys, and some are single isolated hills. In the northeast corner of Lyon county north and west of Little Rock there is a group of these hills, giving a topography that is plainly constructional. Along the course of Willow creek leading west from Calumet in southern O'Brien county there is a row of them. Others either in small groups or as single hills are well distributed over the entire Iowan drift plain. These kamelike hills are more fully treated on pages 90 to 102.

Gravel Benches.—Gravel benches exist along most of the valleys of the Iowan drift plain. Some of them are conspicuous topographic features, as they are continuous for great distances and stand well

[24] Iowa Geol. Survey, Vol. XXVI, pp. 310-318, 1917.

above the level of the streams, but some are merely inconspicuous remnants of terraces or shoulders on the valley sides. They are most prominent along the Little Sioux through Cherokee county and in the lower courses of Mill and Waterman creeks. The dissection of the benches is, as a rule, much sharper than that of the uplands, being of the sharply dissected type of topography described above (pages 44 to 46). All the small creeks cross these gravel areas in narrow, steep-sided valleys while upstream on the upland they may have broad, open valleys. Even the smaller valleys of the Iowan region generally have gravel deposits along their courses, even out near the heads of small streams on the upland. Benches may or may not be present, depending upon the extent to which the stream has cut into the valley filling. The valley gravels are discussed more fully in Chapter V.

Sand Hills North of the Spencer Flat.—At a number of places along the north side of the Spencer flat there is a topography characterized by low rounded hills, with a relief of only 10 to 20 feet. These hills appear at first sight to be glacial, but a closer examination shows that they consist largely of sand and that sandy roads are common in the belt where they are present. As noted on page 43 the poor drainage of the plain just north of Spencer apparently is due in part to obstruction caused by this low ridgelike belt of hills.

This topography begins at the east end of the Spencer flat just west of Meadow brook and extends westward as a low slightly rolling ridge bordering the flat through the north half of section 9, the south half of section 5, and the central part of section 6 of Sioux township. It is present in section 1 of Riverton township and in the north half of section 36 and the northeast quarter of section 35 of Summit township, where some shallow road cuts show exposures of sand. The north half of section 32 and the adjoining parts of sections 29 and 30, Summit township, on the point of upland between the Little Sioux and Stony creek valleys, have a topography of slightly rolling hills with a relief of about 10 feet, and the road on the north line of section 32 is quite sandy. Similar topography and sandy roads are found just north of Everly, and in section 33 and the southwest quarter of section 28 of Waterford township are rounded hills half a mile back from the valley which are said to be composed of sand. Farther northwest at the southwest corner of Osceola county, along the east bluff of the Ocheyedan river valley, there is another belt of low rounded hills composed of sand, and similar features are shown faintly northwest for several miles across Harrison township.

The distribution of these sand-areas to the north of the Spencer flat and to the northeast of the Ocheyedan valley accords with the usual location of eolian deposits on the northeast side of valleys, due to the prevailing southwest winds of our latitude. They probably were formed during the Wisconsin glacial epoch when Ocheyedan river was carrying great floods of debris-laden water from the margin of the Wisconsin ice sheet.

All these areas of sand hills are along the course of the "Altamont moraine" as mapped by Professor Macbride in his discussion of "The Margin of the Wisconsin Drift."[25] They resemble a faint glacial topography and may have been so interpreted by Professor Macbride.

THE IOWAN DRIFT

General Characteristics

The differentiation of the Iowan drift region as distinct from the Kansan and the Wisconsin is based primarily on its topography. The characteristics of the drift itself are so like those of the Kansan drift that general descriptions of the two would be almost identical. It is only by comparing them in detail that differences and distinguishing characteristics can be made out. There are some places where the upper part of a section of drift is fresher than the lower part or differs in some other way, and in such places a twofold division of the drift is suggested.

The more general characteristics of the Iowan till are as follows: It has a brownish gray color where fresh, and on the faces of dry cuts the color is yellowish gray, somewhat lighter than the Kansan till under similar conditions. It is strongly calcareous, even to the surface, there being no leached zone, but near the surface many of the cuts are characterized by a gray calcareous staining along joints and in streaks and blotches through the till, the beginning of alteration. The Iowan till is more sandy and pebbly than the Kansan and, therefore, less compact. Where it is most compact it breaks out in angular chunks which crush down to a mealy clay. The dominant pebble is gray limestone which is, as a rule, fresh and unaltered, although some of the associated coarse-grained igneous pebbles are rotted so as to crumble easily. A common feature is the presence of small, brown, ocherous grains from a sixteenth of an inch to an inch across.

Since the Iowan till generally cannot be separated in sections from

[25] Iowa Geol. Survey, Vol. XII, pp. 329 and 333, 1901.

the Kansan beneath, few data exist as to its thickness. Some of the sections to be given later show 20 to 30 feet of what may be Iowan till, and even more where interbedded with gravel; but it is probable that over most of the area concerned the Iowan till is relatively thin, and that it is in large part reworked Kansan till.

A pronounced characteristic of the till of the Iowan region is its association with much gravel. Some of the gravel is in masses in the till, some is at the surface of the till, some is in layers interbedded with the till, and some is in bedded deposits in the valleys. The gravel in these several positions is very similar and appears to have had a common origin.

Relation to the Loveland Deposits

There are very few exposures of Iowan till associated with other deposits in such a way as to fix the age of the tills. The super-Kansan gumbotil, which forms such a definite key horizon in the Iowan region of northeastern Iowa and in southern Iowa, is not present in northwestern Iowa and there are no other similar, widely distributed interglacial deposits. It is this lack of key horizons that has made it so difficult to conclusively establish the existence of the Iowan drift region.

At various places in western Iowa south of our region there are old loess, silt, and sand deposits younger than the erosion of the Kansan till and older than the general loess horizon of Peorian age. These are known as the Loveland, a term introduced by Shimek in 1909[26] and more definitely defined and limited by Kay in recent years.[27] Kay has now recognized this unit at various places in southern Iowa, beneath the Iowan till of northeastern Iowa and between the Illinoian gumbotil and the Peorian loess of southeastern Iowa. So far as western and southern Iowa are concerned the Loveland could be late Yarmouth, Illinoian, Sangamon or Iowan in age, but the relations in eastern Iowa, where it rests on an eroded surface cut in the Illinoian gumbotil in southeastern Iowa and is overlain by the Iowan till in northeastern Iowa, seem to limit it to late Sangamon time. It is, of course, not necessary that all deposits called Loveland be of exactly the same age.

Deposits which are interpreted as Loveland have been found at sev-

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[26] Bull. Geol. Soc. of America, Vol. 20, Footnote, p. 405, 1909.

[27] 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. Also Iowa Geol. Survey, Vol. XXXIV, pp. 277-281, 1929.

eral places in northwestern Iowa and the horizon will appear in some sections treated under the discussion of the loess (pages 126 and 130) and in some sections treated under the discussion of the Iowan boundary (pages 73 to 78). A few deposits interpreted as Loveland have been found in the Iowan region beneath till which is in turn overlain by the Peorian loess, and these sections, if correctly interpreted, fix very definitely a post-Loveland, pre-Peorian till. These are, therefore, the most important exposures in support of an Iowan drift region.

In the south part of section 19, Cedar township, Cherokee county, the road cut on the south slope of a deep, narrow ravine showed the following:

		Feet
4.	Clay, loesslike. *Peorian*	4
3.	Till, brownish gray, sandy, pebbly, unleached. *Iowan*	8
2.	Sandy silts, blue-gray, calcareous. *Loveland*	8
1.	Till, brown, unleached in upper part, blue-black below. *Kansan* Top few feet exposed in road cut and exposures exist at intervals down the ravine to near Mill creek.	45

The road cut on the north slope of this ravine, 50 yards from the above exposure, showed the following:

		Feet
4.	Clay, loesslike. *Peorian*	4
3.	Gravel, fresh, unleached. *Iowan*	4
2.	Silts, blue-gray, calcareous. *Loveland*	1
1.	Till, brown, unleached. *Kansan*	4

The blue-gray calcareous silts on the south side of the ravine very definitely separate a thin till above from a thick till below. These silts are of the type generally recognized as Loveland, and the upper, lighter colored till must be Iowan. On the north of the ravine the Iowan till is absent but the characteristic fresh Iowan gravels occupy this horizon. These exposures are near the boundary of the Iowan drift region as mapped.

At the southeast corner of section 13, Liberty township, Cherokee county, a road cut on the east slope of Mill creek valley showed the following:

		Feet
4.	Gravel, unleached. *Iowan*	6
3.	Silty material, unleached, blue-gray, with some oxidized sandy layers. *Loveland*	12
2.	Loesslike clay or silt with some sandy layers, brownish. *Loveland* As a whole it seems to be leached but has a few calcareous concretions in the upper part. Locally it is strongly oxidized.	12
1.	Till, brown, oxidized, unleached. *Kansan* This continues below the road level down to the creek.	25

A road cut just north of the southeast corner of the section, just north of the east end of the above exposure, showed the following:

		Feet
5.	Clay, loesslike. *Peorian*	5
4.	Gravel, unleached, gray. *Iowan*	5
3.	Loess, buff, calcareous. *Loveland* Somewhat banded with bluish and brownish bands. A few snail shells were found on the slope.	8
2.	Loess, blue-gray. *Loveland* This contains many snail shells. It extends to the base of the cut.	3

Numbers 3 and 2 of this section are the equivalent of number 3 and possibly number 2 of the first section. Number 5 is above the first section, and the second section does not reach number 1 of the first section. These exposures are at the edge of the Iowan drift sheet as mapped. No Iowan till is shown, but the gravel is a well recognized horizon of this age.

A section west of the quarter-corner on the south of section 4, Carroll township, O'Brien county, three miles southeast of Sheldon, is recorded by Kay and Apfel as follows[28]:

		Feet
3.	Loess, buff	1 to 3
2.	Till, Iowan, highly calcareous, pebbly and sandy, oxidized to yellowish brown color	2 to 3
1.	Loess, Loveland, highly calcareous, plowed into base of till, gray to buff in color	3 to 5

This exposure was found by Kay, Leverett, MacClintock and Apfel in 1925 when the section quoted above was taken. The writer visited this exposure in 1927 in company with Kay, at which time it was so badly slumped and so overgrown with weeds that the above section could not have been made out. However, the several units were dug out locally so that one could recognize at top a leached buff loesslike clay; lower down a calcareous, sandy or gravelly till-like material; and lower still a gray loesslike clay. The writer accepts the interpretation given by Kay and Apfel for this section.

The highway ascending the east bluff of the Little Sioux valley just east of Cherokee showed, in 1927, an interesting series of cuts. The ascent to the upland is made along a grade which cuts a series of spurs between ravines and fills the ravines, and the cuts are successively higher to the east. The first two cuts, beginning at the lower or west end, showed gray unleached Nebraskan till grading upward to leached Nebraskan till or gumbotil. The second cut showed an irregular contact

[28] Iowa Geol. Survey, Vol. XXXIV, p. 279, 1929.

with the Kansan till above, owing to the plowing up of the Nebraskan till by the Kansan ice. This plowing has removed the weathered Nebraskan at some places.

The third cut from the west showed the following section:

		Feet
4.	Clay, loesslike ... At crest of cut it is one foot thick and leached. It thickens down the slopes of the cut to 3 feet, with a maximum leached zone of 2 feet.	2
3.	Till, friable, sandy. Apparently *Iowan* ... At top is a pebble band with several cobbles of quartzite that show wind polish.	13
2.	Till, yellow-brown, unleached. *Kansan* ... Contains several inclusions of Nebraskan till.	20
1.	Till, gray. *Nebraskan* ...	

The fourth cut showed only Kansan till. The fifth cut showed 17 feet of buff and blue horizontally bedded silty material with some sandy layers and a few pebbles. It is all calcareous. In the lower part of the exposure at one place is a carbonaceous soil-like material in which a few shell fragments were found. The cut exposed nothing above or below this material, but the elevation of the cut is entirely covered by the Kansan till horizon of the next cut on the west and the next cut on the east. The silty material evidently occupies a depression in the general horizon of the Kansan till. It is interpreted as Loveland material and may be in part eolian.

The next cut exposed 15 feet of oxidized Kansan till overlain by two feet of fresh Iowan gravel and then by four feet of Peorian loess leached to a depth of two feet. The cut at the crest of the valley slope showed about seven feet of loess leached to a depth of four feet. Below the loess about four feet of yellow pebbly till was exposed and the lower part of this horizon showed a much contorted unit of silty material six to twelve inches thick mixed with the till. The till is apparently Iowan, enclosing in its base some contorted Loveland silts.

This series of cuts exposes from the base upward, Nebraskan till, Nebraskan gumbotil, Kansan till, Loveland silts, Iowan till and gravels, and Peorian loess. They are located approximately at the Iowan boundary.

Some Till Exposures Interpreted as Iowan

Aside from the exposures described above, which include Loveland deposits, the best evidence for the recognition of an Iowan till is found in northern Cherokee county along the Little Sioux river and

Mill creek valleys, and many exposures of this region were studied in detail. Some of the better ones of these exposures will be described.

Doupe Farm.—There are several interesting exposures on the farm of M. Doupe, in the north half of the northwest quarter of section 13, Cherokee township. A sketch map of the area is shown in figure 7. The upland

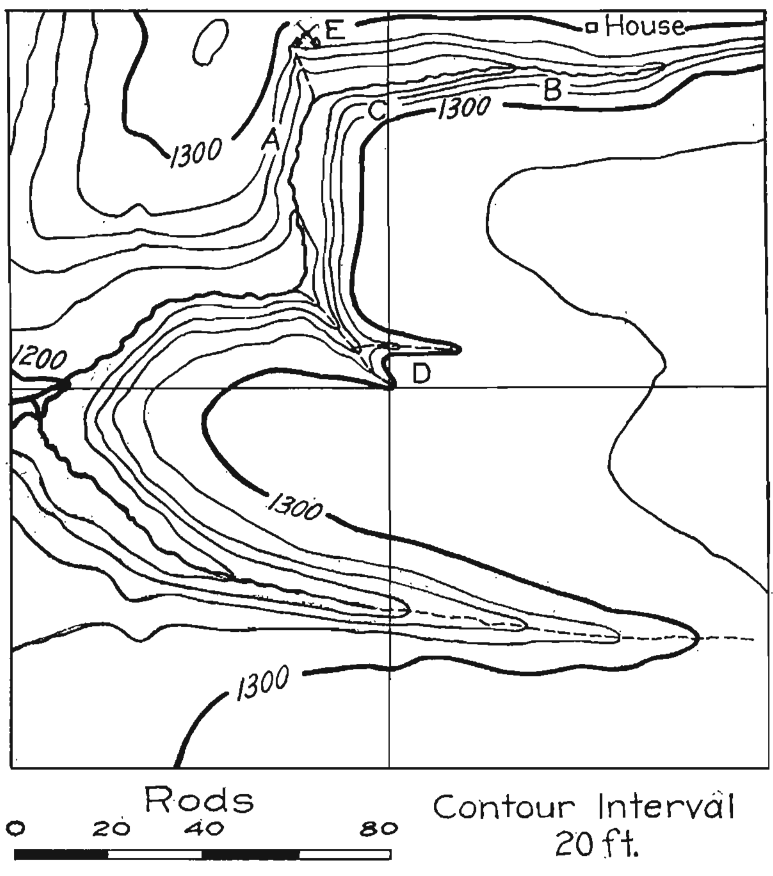

FIG. 7.—A sketched contour map of the northwest quarter of section 13, Cherokee township. The locations of the sections described in the text are shown by the letters A, B, C, etc.

level over most of this quarter section is a bench at an elevation of about 1300 feet above sea level. A ravine enters near the northeast corner and runs southwest across the quarter section as shown in figure 7. Where it enters the quarter section, this valley is only 25 to 35 feet deep, but in the next quarter of a mile it deepens abruptly so that across the west half of the quarter section it has a depth of 80 to 100 feet, and a narrow flood-plain indicates that the stream has here reached grade. The valley sides are very steep for drift slopes and rise directly to the level of the bench. This valley is a good example of the type of recent dissection found along the Little Sioux.

The west slope of the valley, about 20 rods south of the place where the stream turns south in the north part of the quarter section (A, figure 7), exposed, in 1910, the following section. It is shown diagrammatically in A of figure 8.

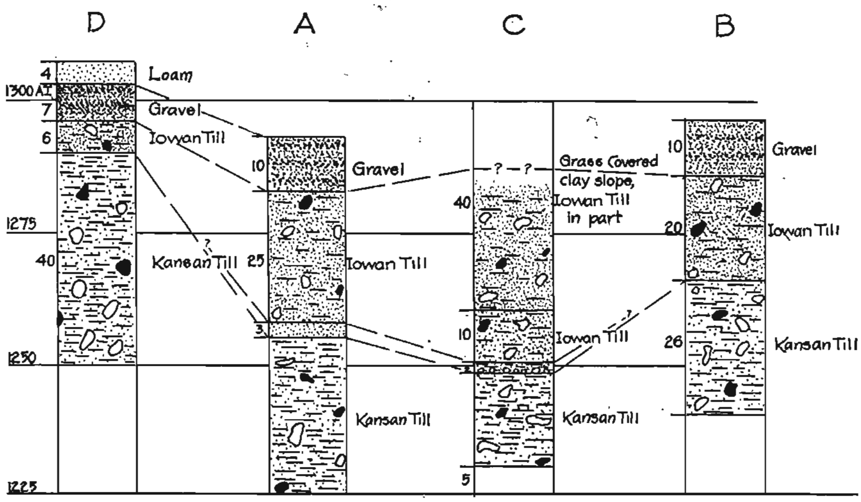

FIG. 8.—Columnar sections of exposures on the farm of M. Doupe in the northwest quarter of section 13, Cherokee township. The locations of the sections are shown by corresponding letters on figure 7.

		FEET
4.	Gravel horizon below terrace bench	10
3.	Till, light brownish gray. *Iowan*	25
	Above is a till slope of 20 feet with a 5-foot vertical face of till below. This till is more sandy and pebbly than the Kansan and therefore less compact. The lower part contains several lenses and seams of sand.	
2.	Sand, dirty, yellow, fine- to medium-grained, with a few pebbles and some clay-balls of the till above	2½
	The contacts with the Kansan below and the Iowan above are sharp and horizontal, and the horizon has a uniform thickness across the exposure, a distance of about 40 feet.	
1.	Till, dark blue, tough, pebbly, weathers brown. *Kansan*	25
	At the top is a vertical face 10 feet high. Below this, a slumped slope of weathered brown till continues down 20 feet to the ravine bed.	

About 20 rods southwest of the Doupe farmhouse, at the point marked B in figure 7, the south slope of the ravine showed the typical dark brown Kansan till rising 25 feet above the ravine bed and overlain directly by the Iowan till, a light brownish gray sandy till with brown iron staining along the joints. This upper till breaks out in angular chunks which break up further into small angular fragments and pulverize to a sandy clay. If quite moist the till is plastic, but the sandy nature is usually evident. Sandy or gravelly material is mixed with the till at several places and both the till and the gravelly material have many limestone pebbles. As at many other places a prominent character of the Iowan is the presence of small reddish brown ocherous grains which pulverize to a reddish brown powder. The Iowan till was freshly exposed for about 12 feet and a till slope rose eight feet higher, giving a total thickness of 20 feet. The till was overlain by 10 feet of fresh gravel rising to the terrace level. The columnar section is shown in B of figure 8. The contact of the Iowan and Kansan tills was exposed at three places covering a distance of about 20 feet and in this distance drops about one foot. At one of the places exposed there is a thin seam of sand at the contact, and at another a zone about one foot thick which is a mixture of the tills above and below. Where no contact phenomena appear, the contact is still distinct, by reason of the contrast of the two tills.

The south slope of the valley on the center line of the quarter section (C, figure 7) exposed the following section, which is shown diagrammatically in C of figure 8.

		Inches	Feet
4.	Pebbly slope with a few exposures of till and sand. This zone appeared to consist of till with several large included masses of sand. The upper part of this slope covers the elevation of the usual gravel horizon beneath the terrace.		40
3.	Till, brownish gray, sandy, with lenses of sand. *Iowan*		10
2.	Sand and silt. This zone consists of the following:		1½
	c. Coarse, ferruginous, laminated sand with a thin band of blue silt at the top	4	
	b. Brown and blue-gray sandy silt like the matrix of the layer below	6	
	a. Blue-gray sandy silt with cobbles and some bowlders up to 10 inches in diameter. The bowlders lie on the Kansan till surface and the silt was apparently put down around them.	8	
1.	Till, mottled brown and bluish brown. *Kansan*. This type of till is produced by the rapid weathering of the blue clay. The upper three to four feet was in a cliff exposure. The remainder was in a slumped slope extending down to stream level.		18

The sand and silt zone (No. 2) was exposed at another place in the slide 25 feet away and showed approximately the same succession of bowlders, silt and sand, but all somewhat more ferruginous. The undisturbed position of the laminæ of sand and the silt band just below the upper till show that there was little wear or shoving by the Iowan ice, for such delicate structures would be difficult to preserve even if the material were firmly frozen.

While ascending the small ravine which heads at the center of the northwest quarter of section 13 (D, figure 7) many exposures of typical brown Kansan till were seen, through a vertical distance of 40 feet, and at the head of the ravine the Iowan-Kansan contact was exposed at several places over a distance of 25 to 30 feet horizontally. The two tills are in direct contact or separated by a thin band of ferruginous sand.

The Iowan till of this exposure is only a few feet thick, but aside from some slight surface alteration and discolorations along the contacts it has the characteristics common for this till. It contains much coarse yellow sand and gravel, and at one place a vertical section showed as much sand and gravel as till. At the top of the till there is, at several places, a zone 6 to 18 inches thick that was either laid in water or partly reworked. The till is overlain by terrace gravels, and along the contact both the basal six inches of the gravel and the top six inches of the till are iron stained.

The terrace-gravel horizon is six to eight feet thick in this exposure and consists of fresh fine-grained gravel with many pebbles, cobbles and bowlders distributed through it. Gray limestone is particularly abundant among the pebbles. The gravel is in turn overlain by dark brown non-calcareous loesslike clay which has a thickness of about four feet and stands with a vertical face which shows columnar jointing. A columnar section of this exposure is shown in D of figure 8.

Besides the exposures already described for the Doupe farm, there are a number of other smaller exposures supplementing and confirming those already noted. At the gravel pit (E, figure 7) the Iowan till and overlying gravels are shown. The road cuts along the north line of the quarter section west of the Doupe farmhouse showed a light yellowish gray till that was distinctly lighter than the Kansan till. The upper few feet of this till contain considerable whitish calcareous material along the joints and in streaks through the till. Where the road crosses the ravine, east of the Doupe farmhouse, in the northwest corner of the northeast quarter of section 13, both valley slopes show the Iowan till overlain by valley gravels.

Pits of Cherokee Sand and Gravel Company.—Across the Little Sioux valley from the Doupe farm, in the northwest quarter of the northeast quarter of section 14, Cherokee township, are the gravel pits of the Cherokee Sand and Gravel Company, in the terrace of the Little Sioux valley. Several pits have been worked in the past on the slopes of a ravine that cuts into the terrace and a pit just south of the ravine was operated to a depth of 40 to 50 feet. All the pits show essentially the same succession. At the top is a gravel horizon a few feet thick; then comes a till horizon four to seven feet thick; and below this is the great gravel horizon which has been worked to a depth of more than 50 feet.

Three abandoned pits, each 75 to 100 yards from the others, are located on the slopes of the ravines, as shown in figure 9. The till horizons of the

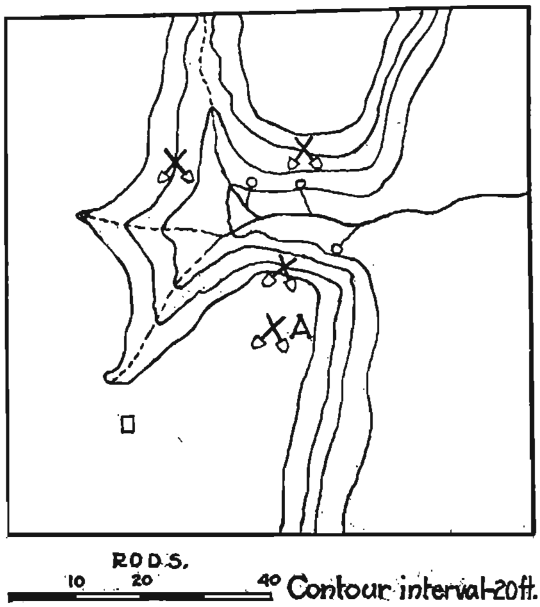

FIG. 9.—Sketched contour map showing the location of gravel pits on the farm of F. R. Turner (northwest quarter of the northeast quarter of section 14, Cherokee township). The pit *A* was operated by the Cherokee Sand and Gravel Company.

three exposures are of practically identical material, are at approximately the same altitude, and have the same thickness, so that there can be little doubt that the till was once continuous across the intervening valleys over an area at least 75 to 100 yards across. The mass is too large to have been floated in by ice and must have been laid directly by the Iowan ice sheet. The till horizon is thinner in the pit on the terrace just south of the ravine and is said to be absent entirely beneath the terrace a few rods farther south.

This till has a light brownish gray color, shows brown iron staining along the joints, and contains many small, reddish brown ocherous grains. Pebbles and cobbles are scattered through the till. Limestone is the dominant material among the pebbles, and it is mostly fresh and firm, while the coarse-grained igneous pebbles are decomposed and crumble easily. These several till exposures differ slightly because of different conditions of moisture, exposure, etc., yet in the main they are similar and all have the characteristics of the Iowan till.

The contact of the till with the gravel below is very sharp and there is no alteration whatever, both the till and the gravel being distinct to the very plane of contact. In one exposure, extending 30 to 40 feet horizontally, a six-inch layer of coarse sand underlies the till directly and yet not the least distortion or mixing is shown. The contact does not appear to have been produced by planation by the ice and may represent an aggraded surface covered by till without disturbing the material below. The contact of the till with the gravel above is not so well shown as is the lower contact, but enough was seen to show it has some irregularities. The overlying gravel, where thin and coarse, is weathered and iron-stained throughout its entire thickness.

Other Exposures.—In the east bluff of Mill creek valley in the west half of section 14, Cherokee township, there are a number of exposures showing gravel and till interbedded. The till in the upper, steeper part of the bluff is Iowan, a brownish gray or brownish yellow clay with pebbles, cobbles and small ocherous masses. These exposures are more fully discussed on pages 84 to 89.

Many exposures north of the Cherokee region show a till that is not typical Kansan, and yet from the small exposures it was seldom possible to identify them positively as Iowan till. They are numerous in northeastern Cherokee, southeastern O'Brien, southwestern Clay and northwestern Buena Vista counties, and less abundant elsewhere throughout the Iowan region. Many of them will be noted in connection with the tracing of the Iowan drift boundary.

In Spring township of northeastern Cherokee county the brownish gray Iowan till was seen on the south lines of the southeast quarter of section 31 and the southwest quarter of 32; along the road leading down to the Little Sioux valley north of the center of section 29, where a 15-foot exposure of Iowan till rests on a sand horizon containing a lot of clay masses; in the upper part of the bluff south of the center of section 21, where it is apparently 50 feet thick; and in the west part of section 12, 75 to 100 yards southeast of the point where the road crosses the creek, the east slope of the valley shows at the top about 40 feet of Iowan till resting on sand, while Kansan till forms the lower part of the slope.

In Brooke township in northwestern Buena Vista county examples of fairly definite Iowan till were seen in road cuts on either slope of a ravine near the quarter-corner on the south of section 22, in the road cut at the top of the east bluff of Brooke creek on the north line of section 25, and in the cuts on the east of sections 17 and 8. The west bluff of Brooke creek on the north of section 23 showed a mixture of sand and possible Iowan till.

Probable Iowan till was seen in shallow cuts in various parts of O'Brien county. Along Willow creek in Liberty township such exposures were found in the south bank of the creek at the southeast corner of section 17 and in the road cut just east of the quarter-corner on the south of the same section. The road cut in the south slope of this valley on the west line of section 20 showed the typical brownish gray Iowan till, with much gravel interbedded and in pockets, while down the slope near the creek and north of the creek a yellowish brown till that is apparently Kansan was exposed. Probable Iowan till was seen in the railway cuts of section 6 and 7, Highland township; as material thrown from a well in the southwest quarter of section 31, Summit township; in excavations at Hartley; and at many other places.

West and northwest of Sheldon there are several exposures of probable Iowan till which will be noted in tracing the Iowan drift boundary (page 65). The till exposed in excavations at Sibley is very fresh and, in fact, this is the general condition everywhere in the northern part of the Iowan drift area.

South of the Wall Lake outlet in southern Sac county, in the banks of a small creek valley which follows the Wisconsin drift boundary in the west part of section 20, Viola township, two tills are exposed. The lower is Kansan. The upper has a yellowish gray color where dry and brownish gray where moist. It breaks into flakelike pieces, crumbles to a mealy clay and contains many more pebbles than the Kansan. Its contact with the Kansan below is relatively sharp and it has a thickness of more than 20 feet. This till is almost identical with the till that overlies the Kansan north of Cherokee and is there called Iowan till. If seen elsewhere in the Iowan area, it would be interpreted as Iowan, but being here so close to the Wisconsin drift area, there is a possibility that it is Wisconsin drift. Near the northeast corner of section 30, Viola township, there is a roadside exposure of yellowish gray pebbly till that may be Wisconsin drift, but it would fit the Iowan drift better, and it is one-half mile west of the creek valley which forms the west limit of the Wisconsin drift topography.

THE IOWAN BOUNDARY

The discussion of the Iowan boundary which follows is based primarily on the work of 1913 and is essentially as given in the manuscript of 1915. The tracing of this boundary in the field progressed from north to south and the same order is followed in this description. This order was followed in the field because Leverett had definitely established the division in southwestern Minnesota and because its distinctness is strongest there and near the state line, decreasing southward.

In order to become familiar with the characteristics of the Iowan and its boundary in this more definite region, the writer studied the Iowan area from the state line in western Nobles county, Minnesota, north beyond Adrian, having at the time a tracing of the boundary as mapped by Leverett.[29] The marginal portion of the Iowan region through western Nobles county is a broad, elevated ridge having at places distinctly constructional topography. In general this marginal belt becomes less pronounced from Adrian south to the state line, but all the region seen by the writer in Nobles county is positive, and the boundary is definite.

From the State Line to Little Rock River.—The elevated area that runs southward from Adrian, Minnesota, continues into the north-central part of Elgin township in the northeast corner of Lyon county. It there becomes indefinite and broken up, on the slopes of Little Rock river valley, and south of the Little Rock it is no longer sufficiently prominent to be mapped as a morainic belt separate from the Iowan drift plain. In fact, the east boundary of this marginal belt north of the Little Rock is quite indefinite, and a marginal belt, separate from the Iowan drift plain, is not shown on Plate I. The course of the boundary southward through west-central Elgin township is shown on Plate I.

To the north and west of the village of Little Rock there are a number of kamelike gravel hills, forming probably the most pronounced development of these features found in the Iowan area south of the state line. In general they rise only 10 to 15 feet above their surroundings, but one in the southeast quarter of section 23 rises 25 feet above its surroundings, so as to be a rather prominent feature, especially from the valley to the south. It is figured in the Lyon county report[30] and is there interpreted as part of the Altamont moraine. In the southwest part of section 27 the topography is plainly constructional, with a number of gravel hills, and a dozen or more low swells with pebbly surfaces appear west of the center of section 34.

The boundary of the Iowan drift crosses the state line into the northeast part of section 7 of Elgin township and runs southeast through the south-

[29] Later published by Leverett and Sardeson on Map of Surface Formations of Minnesota, Sheet 3: Minnesota Geol. Survey, Bull. 14.
[30] Iowa Geol. Survey, Vol. X, p. 133, 1900.

west corner of section 8 and diagonally across sections 17 and 21, the boundary lying a short distance to the west of a westward facing slope (Plate I). The railway through section 17 follows along the base of this slope and along the Iowan boundary. In the southeast quarter of section 21 the boundary turns southward and through the east part of section 28 is one-fourth to one-half mile west of a crest along the section line. West of this crest the southwestern part of Elgin township is slightly rolling, sloping gently to the west. East of the crest the region is more rolling and the relief is in part at least constructional, including the gravel hills of sections 26, 27 and 34. Gravelly swells appear also at several places in the northeast quarter of section 33, just east of the quarter-corner on the south line of section 33, and south of this corner in section 4. The boundary runs south through the center of section 33 and section 4, Grant township, to Little Rock river valley.

Along Little Rock River and Otter Creek.—Crossing to the east side of Little Rock river valley in section 4, Grant township, the boundary follows the valley southward across Grant township and southwestward across the northwest corner of Dale and the northeast part of Wheeler townships to the entrance of Otter creek in section 21 (Plate I). In the southern part of this course in Dale and Wheeler townships the boundary bends westward 5½ miles in making 3½ miles to the south.

In this course along Little Rock river a slight difference in the topography is noted in passing from one side of the valley to the other. To the west the region has more open valleys with long smooth slopes and definite divides, affording long views either along or across the valleys. To the east the larger topographic features still seem to be due to pre-Iowan erosion, and the area is well drained, but the valley slopes are not so smooth, and the valleys are somewhat obstructed, giving to the whole region a more billowy surface. The difference is not such that one can identify each quarter section as belonging to one or the other division, but larger areas must be considered. There is nothing along this margin to suggest the marginal morainic belt that exists farther north, and in fact much of the central part of Grant township has very few constructional features in its topography. More characteristic Iowan drift topography is found farther east along the county line and in West Holman township of Osceola county.

Eastern and central Grant township drains by westward flowing streams to the Little Rock. The relief is 30 to 50 feet and the surface is moderately rolling. Although there are quarter sections or even whole sections that are indecisive, the whole of the township east of the river has been included in the Iowan. Some of the evidence for bringing the boundary westward to the valley is as follows: The northwest part of section 9 has an undulating surface, with poorly drained depressions, sandy material at places, and bowlders on the slopes of the valley. The valley slope on the west line of section 9 showed gravel overlain by a mixture of till and gravel, the till being of the type that is considered Iowan. The southwest quarter of section 9 has an undulating surface on the valley slope and the southwest part of section 16 shows the same features to a less degree. At the quarter-section corner on the south of section 20, at the very edge of the valley is a gravel mound cut by the road grading, and several other pebbly swells are found in the field just north of the road. There is an undulating surface just southeast of the center of section 20. The soil is in places sandy, as on the east of section 29, the north of section 20 and elsewhere in Grant township, and pebbles appear on many low swells or are exposed in shallow road cuts. All these are characteristic features of the Iowan drift but not of the Kansan of this region. Besides these more specific cases along the valley margin there is, as noted above, the general undulating surface of all the region to the east of the river.

Along the east side of the valley through Wheeler township there is very conclusive evidence that the Iowan region extends to the valley's edge. A billowy surface is found in many places, sandy material is present in the soil, and a few bowlders lie on the surface. In the north half of the southeast quarter of section 11, south of George, the surface is billowy, and similar topography appears also in section 23, the east part of section 21, section 27, the north part of section 35 and elsewhere. Sandy places exist along the roads on the west of sections 14 and 23 and on the north of section 27, and pebbly surfaces were seen in the northeast quarter of section 27, the southwest quarter of section 22, the southeast quarter of section 21 and the northeast quarter of section 35. Some of these gravelly places are on low swells that are evidently gravel hills. Bowlders lie along the fence rows at several places, as near the southwest and southeast corners of section 22 and around the northwest corner of section 36. The evidence therefore seems conclusive enough that the ice pushed out to the valleys across Wheeler township, even into section 21.

Eastern Wheeler township for several miles east from the valleys is much like the central part of Grant township; moderately rolling, well drained, and with only the scattered bits of evidence noted above that the Iowan ice covered it. To the east the topography becomes less rolling and in Dale township a typical development of the slightly rolling Iowan drift plain with a relief of 10 to 20 feet is found. In no place is there a topography of terminal moraine aspect.

In section 21 of Wheeler township, Little Rock river is joined by Otter creek, which enters from the southeast. At the union of these valleys the Iowan boundary changes its direction to southeast and follows up the northeast side of Otter creek valley across southern Wheeler township and across the northeast corner of Sheridan township, Sioux county, a distance of about five miles (Plate I). Here, in section 7 of Grant township, southwest of Matlock, Otter creek changes its direction and heads off to the northeast, but the Iowan drift boundary crosses the valley and continues its course southeast.

Gravel deposits appear along Little Rock river and Otter creek valleys where they flow along the drift margin and to a less extent along Otter creek and Rat creek within the Iowan drift area. There are low benches at many places along Little Rock river, remnants of the valley filling. The general width of the flat of this valley is about half a mile, most of which is below the bench level.

After the change of direction at the mouth of Otter creek the Iowan drift boundary holds a regular course east of south across several counties (Plate I), a course parallel to that across southwestern Minnesota. Between these two parts the boundary curves westward in eastern Lyon county, extending into the angle between Little Rock river and Otter creek. In Minnesota the ice which reached the Iowan drift boundary had to cross the high area known as the Coteau des Prairies. This high area breaks down in southern Nobles county, and south of this region the ice moving obliquely toward the boundary had an easier course and was able to push farther to the west. The ice that crossed the line of the Coteau des Prairies in southern Nobles and northern Osceola counties probably reached the boundary in southern Lyon county, causing the westward bend described above. The ice found in western Osceola county a rather level upland and in Dale township a very level plain, so that it was able to push out to the valleys of Wheeler township.

Alternative Boundary in Lyon County.—West of the boundary traced through Elgin township and extending westward for about two miles into Midland township and covering the contiguous corners of Liberal and Grant townships to the south, is an indefinite area included in Wilder's "Wisconsin, Partially Stratified" unit (figure 3). It has an even surface in part, sloping gently westward, and there is considerable gravel along the stream courses. The topography is, in general, more like Kansan than Iowan but somewhat filled up by gravel along the stream courses. Till exposures were seen on the west lines of sections 20 and 17, Elgin township, but they are of the questionable type, neither distinctive Kansan nor Iowan. Some low gravel hills on the north of section 36, Midland township, and gravel deposits around the northwest corner of the same section suggest Iowan. The west half of Midland township has definite Kansan topography and till. It seems better to leave this indefinite area of western Elgin and eastern Midland townships in the Kansan region, but modified by Iowan outwash.

Northwest of George in sections 34 and 27, Liberal township, there is a north-south ridge and in section 26 a hill that may be constructional, but they are not positive. A similar northeast-southwest ridge exists in section 19, Grant township. These features suggest that the Iowan ice sheet crossed Little Rock river valley in Grant township and had its edge in eastern Liberal township. A suggested boundary that would include these possibly constructional ridges northwest and northeast of George, as well as some of the indefinite area of western Elgin township, is shown on Plate I. It is three to four miles west of the boundary traced above, in southwestern Elgin and Grant townships. It passes along the west side of the ridge northwest of George and thence south to join with the boundary traced above, at the mouth of Otter creek.

This alternative boundary would bring within the Iowan the possibly constructional ridges near George but has little else to support it farther north. It would not bring into the Iowan the whole of the "Wisconsin Partially Stratified" unit of Wilder. To do so would require a north-south boundary through the centers of Liberal and Midland townships. The boundary traced in the foregoing section, which follows the Little Rock river valley, uses, more consistently, those characteristics upon which the boundary is based to the north and south.

From Otter Creek to Floyd River.—After crossing Otter creek southwest of Matlock, the boundary runs southeast across Grant township and reaches Floyd river in the northeast corner of Lynn township, southwest of Sheldon (Plate I). For most of this distance the boundary is well defined, being marked either by a southwestward facing slope or by a ridge that overlooks the region in either direction.

To the northeast of the boundary the central part of Grant township has a characteristic Iowan drift topography of slight relief and undulating surface, with locally, as in the east half of section 16, a tendency toward marshiness. To the northwest along Otter creek and to the southeast along Floyd river the relief is greater and the Iowan drift characters are not so well defined.

Outside the boundary the Kansan drift topography is characterized by broad, open valleys with long, smooth slopes. Sheridan township, southwest of Otter creek, has a moderately rolling erosional topography near the valley, but to the southwest this passes into an upland of slight relief which covers the central part of the township. This upland has less relief than most of the areas of Iowan drift, but here all the valleys are broad with smooth slopes and head in a level plain.

The course of the boundary is not well defined through section 7, Grant township, just south of Otter creek, but in the northwest quarter of section 17 a ridge or southwestward facing slope begins and continues southeast through the southeast part of section 17, the southwest corner of section 16 and the northwest quarter of section 21 and dies out in the south part of section 21. A similar slope appears again in the northeast quarter of section 28 and continues either as a front or as a ridge diagonally through sections 27 and 35, across the northeast quarter of section 2 and the west part of section 1 of Lynn township to Floyd river (Plate I). In the southwest quarter of section 16 the outer slope of the ridge rises 30 feet in a short distance, the crest is about 200 yards wide, and a slope leads down to the Iowan plain to the east. Through section 27 the front has an altitude of 15 to 20 feet.

Opportunities for observing the drift are few along this part of the boundary. In the material thrown from a well on the south line of section 6, Grant township, two tills were apparently represented, and in the southwest quarter of section 16 ash-colored sandy till with pebbles, apparently Iowan, continues to the surface of the ridge which here forms the boundary. The sandy material found at many places along the boundary farther north does not appear south of Otter creek, but pebbles were found along the ridge in the southwest part of section 16. The boundary here is largely a topographic boundary, but it is sufficiently well defined, being marked by the contrast of the topographies to the northeast and to the southwest and for most of the distance by a ridge or a low southwestward facing slope.

From Floyd River to Mill Creek.—Crossing Floyd river southwest of Sheldon the boundary continues southeast across southern Carroll, northeastern Baker, southwestern Dale and northwestern Union townships, O'Brien county, to Mill creek southwest of Paullina (Plate I). On the county line south of Sheldon there is a low ridge along the border, and its crest overlooks, to the southwest a thoroughly dissected Kansan drift plain, and to the northeast a slightly rolling, billowy Iowan drift plain in which the location of the drainage courses is not distinct. The contrast of the views to the southwest and northeast from this ridge is one of the best along the Iowan drift boundary. In the southwest corner of Dale township the boundary comes into the valley of Mud creek and follows down this valley to Mill creek.

The Iowan drift boundary crosses Floyd river in the northwest quarter of section 12, Lynn township, Sioux county. It thence runs southeast through the southwest quarter of section 12 and the northeast quarter of section 13 along the base of the outer slope of the low ridge noted above. Continuing into Carroll township of O'Brien county, it passes through section 18, the northeast part of section 19, and the south part of section 20, marked by a low swell with a low front to the southwest. To the northeast, sections 18, 17, 20 and 21 have a slightly rolling, billowy Iowan surface, while to the southwest the valleys are broad and the slopes smooth.

The boundary through southern Carroll and northeastern Baker townships is less definite. Low northwest-southeast ridges in the northwest quarter of section 27 and the southwest quarter of section 35, Carroll township, and the southwest quarter of section 1, Baker township, suggest a boundary along this course, but the topography and an exposure on the east line of the northeast quarter of section 33, Carroll township, indicate that the ice really advanced one-half to one mile southwest of the low ridges. The boundary is mapped as running southeast through the northeast part of section 29, the southwest corner of section 28, the northeast part of section 33, and the southwest corner of section 34, Carroll township, and continuing through the northeast quarter of section 3, the southwest quarter of section 2, the northeast quarter of section 11, the southwest quarter of section 12 and the east part of section 13, Baker township. In these sections there is not even a low front at the Iowan drift margin, and the Kansan drift region just outside the boundary is only slightly rolling and in part is even more level than the Iowan, where the latter has its usual development.

An interesting shallow roadside exposure existed about 80 rods south of the northeast corner of section 33, Carroll township, in 1927.

The relations of the several parts exposed are shown in the sketch forming figure 10. A low mound cut across by road grading consists

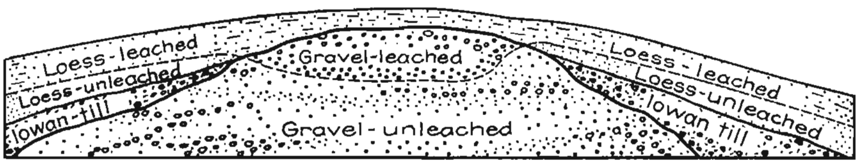

FIG. 10.—Sketch of a roadside exposure about 80 rods south of the northeast corner of section 33, Carroll township, O'Brien county, showing the relations of Iowan till on the flanks of a low gravel mound to the overlying loess and to the gravel below.

largely of gravel. On the flanks Iowan till overlies the gravel, wedging out up the slope before reaching the top. The mound is covered with a coat of loess about three feet thick on the lower slopes but thinning toward the top of the mound, as is usual, to less than two feet and becoming somewhat sandy. The depth of leaching in the loess is about two feet which, over the crest of the hill, is sufficient to go through the loess into the gravels. The gravel beneath the till and beneath the unleached loess is unleached, but over the center of the hill where the loess is entirely leached the gravel below is leached to a depth of four feet below the surface. The relations between the leached and unleached gravels and between the other units show clearly that leaching has progressed much more rapidly in the gravel than in the loess or other more compact materials. The till and gravel are of the type more definitely recognized as Iowan and show that the ice pushed this far southwest. About half a mile farther south on the west of the southwest quarter of section 34 the roadside cut showed beneath the soil one foot of fresh gravel over brown till, with many calcareous concretions, which should be Kansan. The boundary is drawn between these two exposures.

A low ridge, barely recognizable on the east line of Baker township, continues southeast into Dale township through sections 18 and 19, and increasing in size southward, becomes a ridge of some prominence in the east part of section 30, the southwest quarter of section 29 and the central part of section 32. The topography along this ridge and to the east in sections 18 and 19 is plainly constructional. The Iowan drift boundary lies along the west base of this ridge across the southwest quarter of section 18, the west-central part of section 19, the east-central part of section 30 and along the line between sections 31 and 32. Near the southwest corner of section 32 a creek bank showed three feet of loess, leached nearly to the base, resting on three feet of fresh gravels of the Iowan type. In the northeast quarter of section 31, Mud creek, which has had a northeasterly course for four miles, is within one mile of Mill creek, from which it is separated by the ridge 40 to 50 feet above it which marks the Iowan drift boundary. The creek here turns sharply to the south and flows 3½ miles before joining Mill creek.

In northern Union township a billowy glacial topography appears on the elevated area separating Mud creek from Mill creek, and the boundary follows the east slope of Mud creek valley through sections 5, 8 and 17 to Mill creek valley. Shoulders of sand and gravel begin to appear in Mud creek valley in section 5 and become more numerous southward until in section 17 an almost continuous bench borders either side of the valley at an altitude of 20 to 25 feet above the stream. The road on the east line of section 17 is on this bench, and the road cuts show many exposures of dirty sand and gravel. Bowlders were seen in the northeast quarter of section 17, at the southwest corner of section 9 and along the road south of the center of section 9.

Along Mill Creek in Southern O'Brien and Northern Cherokee Counties.—In southern O'Brien and northern Cherokee counties the region to the east of Mill creek shows in most places the characteristics of the Iowan drift plain, while the region to the west shows those of the Kansan. The boundary, therefore, for this distance of 15 to 20 miles from the mouth of Mud creek, southwest of Paullina, southeast to Little Sioux river is placed along the east edge of Mill creek valley (Plate I). If this were the margin of a drift sheet of more pronounced characteristics the boundary probably would be found to run in general along the east side of the valley but not always exactly at its edge; but with a drift sheet of this type there is nothing definite enough about the boundary to justify minor irregularities, and it has seemed better to draw a more generalized boundary, following the valley edge. In several places the Iowan topography comes up to the edge of the valley and it generally can be recognized within one to two miles of the valley, but it would not be possible to prove that the Iowan ice reached the valley at all places.

West of Mill creek the well dissected Kansan topography with broad, open valleys and rounded slopes is found. Farther back to the southwest the relief decreases and the topography passes into the more level upland type of Kansan plain.

A prominent characteristic of Mill creek valley is the presence of great gravel deposits along it. These begin as filled-in areas west of Primghar, where the creek has cut little more than a channel into the aggraded plain. Southward the cutting below this plain increases and shoulder-like benches appear along the valley sides. At the county line the benches are 50 feet above the creek, and near the mouth of Mill creek they stand 90 to 100 feet above the stream (figure 23). The gravels of these benches are discussed further on pages 156 to 158. Great quantities of gravel have been removed in the excavation of the immediate valley of the present stream, and when these are taken into consideration along with that which still remains in the benches, we get some conception of the enormous quantity of gravel that was deposited along Mill creek valley by the waters that flowed out from the Iowan ice front.

Mill creek valley was a stream valley in pre-Iowan times, for it has a long slope leading down from the west. In two places, however, the creek may have been diverted locally. One of these is in southern O'Brien county south of Paullina, from the mouth of Mud creek to the mouth of Nelson creek; and the other is in Cherokee township, from the north part of section 10 to the mouth of Mill creek.

Just opposite the mouth of Mud creek, southwest of Paullina, a high ridgelike area begins and continues, with several minor offshoots, southeast through sections 21, 28, 27, 34 and 35, terminating just south of the county line. The area is almost surrounded by valleys, has a relief of 30 to 50 feet, and drains outward in all directions. Its characters are not positive and it may be questioned whether it should be included within the Iowan. If it is not included, the boundary should pass from the mouth of Mud creek east along Mill creek across section 16 and southeast along a low course diagonally across section 22 to Nelson creek valley and thence down this valley through sections 26 and 36 to Mill creek valley.

The crests of this high area stand at an altitude of 85 to 100 feet above Mill creek, which bounds it on the north, west and south, and above Nelson and Willow creeks on the east. Because of this greater relief the billowy topography characteristic of the Iowan drift is not present and yet the drainage courses are not the broad, open valleys characteristic of the Kansan. At several places erosion has just started to notch the slopes, and sections 21, 28 and 27 show faint indications of Iowan drift. After considering in the field all the possibilities, it seemed best to include this elevated area of south-central Union township in the Iowan and place the boundary along the east slope of Mill creek valley.

South of the mouth of Nelson creek there is fairly conclusive evidence that the ice pushed up to the east edge of Mill creek valley, on south to its union with the Little Sioux. Central Cedar township has typical Iowan topography and in most places this continues to within one to two miles of the valley and locally up to its very edge. Along the township line on the west of section 18 an area only three-fourths of a mile from the valley is slightly rolling over an extent of 40 acres; and there are similar areas near the valley in the central part of section 19, in the southwest quarter of section 28, in the north half of section 33, and in the central part of section 3 and the southwest quarter of section 11 of Cherokee township.

A cut on the east side of a ravine on the north line of the northwest quarter of section 20, Cedar township, shows lighter colored till, probably Iowan, over a yellow-brown till that is certainly Kansan. Other exposures of till interpreted as Iowan along or near this boundary are noted on pages 56 to 58 and 84 to 89 of this report.

From the Mouth of Mill Creek Southeast to Maple River.—At the mouth of Mill creek the Iowan boundary comes to the valley of the Little Sioux, and from here southward past Cherokee and southeast to Maple river the location of the boundary is quite uncertain. The Iowan ice pushed up to the edge of the Little Sioux valley, southward to a point opposite Cherokee, for the billowy Iowan surface is well developed in sections 13 and 24, Cherokee township, and in the southwest quarter of section 25 at the very edge of the valley. The edge of the ice probably was within the Little Sioux valley southward across sections 23 and 26 to Cherokee, for deposits exposed along Spruce street in the north part of the town appear to be Iowan drift (page 71).

The region east and southeast of Cherokee in southwestern Afton and northwestern Pitcher townships has a billowy topography of the Iowan type, while the region south of Cherokee in northeastern Pilot township has a well dissected erosional topography. The boundary between the two regions is not very definite but a comparison of the topographies usually serves to locate it within a mile or less. The position of the boundary as mapped on the basis of topography is shown on Plate I.

The Iowan drift boundary as here mapped leaves the Little Sioux valley east of Cherokee, where the valley swings to the southwest, and runs across section 36, Cherokee township, the northeast quarter of section 1 of Pilot township, and the southwest quarter of section 6, Pitcher township. On the north line of section 7, Pitcher township, the front is marked by a rise of 20 to 25 feet where the boundary crosses from the Little Sioux to the Maple river drainage. The boundary thence passes through the west-central part of section 7 and, with less definite characters, through the east part of sections 18 and 19, to the Maple river valley in the southwest quarter of section 20 (Plate I).

Alternative Boundary just South of Cherokee.—The tracing of the Iowan boundary from the mouth of Mill creek to Maple river is based upon the same criteria as the boundary to the north and south. There are, however, certain deposits at and south of Cherokee that suggest a different boundary farther west than the one traced above. Because these deposits bear primarily upon the location of the Iowan boundary, they will be discussed here as a basis for the statements concerning an alternative boundary.

A cut on Spruce street, just east of Second street, in the north part of Cherokee, within the area of the higher bench level, showed a great diversity of material including gravel, sand, bowlders and till layers. There are many alternations of the material horizontally and vertically. The gravel is coarse, dirty, and contains many large bowlders. Clay-balls are abundant, and in some horizons there is only a little gravel as matrix between the large clay masses. One bed appeared to be till, but when it was dug into, the material separated into rounded masses of till which are packed together without matrix. Also there are lenses or layers of Iowan till, too large to have been floated in, which must have been deposited directly by the ice. The upper seven or eight feet of the cut showed the more common valley gravels overlain by loess. This exposure, which is in the northwest quarter of the southeast quarter of section 27, could be accounted for as Iowan by the very probable interpretation that the part of the Iowan ice sheet within the Little Sioux valley pushed a little farther southward than did the ice on the broken edge of the upland just to the east. This outcrop does not require an alternative boundary.

One hundred yards northwest of the Illinois Central Railway roundhouse, in the southwest part of Cherokee, an abandoned pit on the valley slope showed about 10 feet of yellow sand and gravel overlain by about 25 feet of till, which is apparently Kansan. A slope, apparently of till, rises about 20 feet higher to a high bench of the Little Sioux valley, underlain by at least a few feet of gravel. The till is chiefly blue-gray pebbly clay as fresh, oxidizing to yellow clay with iron staining along the joints. It contains many calcareous concretions and has much sand and gravel mixed through it.

The possibility of this being an exposure of Iowan till over sand and gravel, all laid down in the Little Sioux valley by a slightly greater extension of the prong of Iowan ice within the Little Sioux valley suggested above, was fully considered in the field. The till, however, is not the type commonly called Iowan and its thickness is greater than any known thickness of undoubted Iowan.

The base of the sand and gravel was not exposed, but the exposure is but slightly above the bench upon which Cherokee stands and which is underlain by Nebraskan till. The till above the sand and gravel is, therefore, at the horizon of the Kansan of this region, with which it agrees in its characteristics. Such an interpretation would place the sand and gravel at the Aftonian horizon, but they are calcareous and not notably altered at the contact with the till above. They are believed to be outwash in front of the advancing Kansan ice sheet, which then deposited a thick till horizon over the sand and gravel. The gravel is more highly oxidized than the usual valley gravels and the limestone pebbles are more or less altered. In a pebble count of 100 pebbles, 45 were limestone, but of these only three were classified as fresh compact limestone. The till and the underlying sand and gravel are interpreted as Kansan.

The east-central part of Pilot township south of Cherokee is sharply dissected by several small creeks that head in the east part of the township. Along these creek valleys are a number of exposures of sand and gravel, silt, till, etc. The north one of these creek valleys in sections 10, 11 and 1 heads in the Iowan region as the boundary is traced above, but its branches from the south and the other ravines farther south do not reach the Iowan area as mapped. This is a questionable area lying just outside the Iowan boundary as traced above, or it may be included in the Iowan region by placing the boundary farther southwest. The silts are in general of the type found in valleys at various places in northwestern and western Iowa and assigned to the Loveland (page 49). With these silts, in the valleys of northeastern Pilot township, an unusual amount of gravel is associated and interbedded, and this gravel is, in general, like that of the Iowan region.

The most northern one of these creeks heads in the southwest corner of Afton township and flows southwest diagonally across section 1, the north part of section 11, and the central part of section 10, Pilot township. Its head is within the Iowan boundary as traced above, across the northeast part of section 1, and the usual valley gravels are present along the valley in section 1, overlain by the loesslike clay. Farther down the valley some exposures show a considerable thickness of clean, fine gravel and quartz sand, as in the railway cut in the northeast quarter of section 11, and above a prominent spring zone on the south side of the valley near the west line of section 11. In other exposures silts and silty sands predominate.

The higher terrace of the Little Sioux valley continues into the lower end of the valley in section 10 and is represented by gravel benches up the valley almost to the township corner. Similar benches are also present along tributary branches from the southeast in section 11. In its lower course this creek valley is down in the horizon of the Nebraskan till and in section 10, where the creek crosses the terrace area of the Little Sioux, there are exposures of this till 30 to 50 feet above the creek bed. The gravels of the Little Sioux bench here rest on the Nebraskan till.

In the southeast corner of section 2 at the union of a ravine from the north with this creek valley the following section was exposed:

		Feet
7.	Gravel, fresh, unleached	4
6.	Clay, buff, noncalcareous, loesslike, silty	4
5.	Loess, blue, noncalcareous, silty	1
4.	Sandy silt and fine sand, buff, noncalcareous	2
3.	Silt, dark blue, noncalcareous	5
2.	Sand, brown, noncalcareous, with blue silty bands	3
1.	Gravel, coarse, unleached, with cobbles and bowlders	3

The fresh calcareous gravel at the top (No. 7) is interpreted as Iowan. Zones 6 to 2 below form a unit of calcareous silts and silty sands 15 feet thick and are interpreted as Loveland. It seems more probable that they accumulated as noncalcareous sediments derived from leached surface materials, rather than that they have been leached in place, especially since the next horizon below (No. 1) is a calcareous gravel but contains no calcareous concretions. Number 1 is also interpreted as Loveland. Its base was not exposed, but it probably rests upon till as does the similar horizon (No. 2) of the succeeding section.

Farther up this creek near a railway bridge in the southwest corner of section 1, the bank shows about 12 feet of the Loveland horizon consisting of blue, silty material above and brownish blue, humus-bearing material below, with some snail shells.

An exposure in the west bank of the creek south of the east end of a railway cut in the northeast quarter of the northeast quarter of section 11 showed the following:

		Feet
8.	Clay, brown, weathered, including soil above	2½
7.	Silt, blue-gray, and brown, sandy silt	2
6.	Silt, blue-gray, with some sandy silt	3
5.	Sand, yellowish, fine-grained, with a few bands of dark blue-gray silt	2
4.	Silt, dark blue-gray, sandy	2½
3.	Sand and silty sand with some pebbles	1½
2.	Gravel, very coarse, with cobbles and bowlders	5
1.	Till, light brown, gummy. *Nebraskan*	13

The material is quite variable and a section a short distance laterally might be quite different in details. Zones 4 to 8 are the type of material that characterizes the Loveland and zones 2 and 3 below must go with the Loveland also. The whole makes a thickness of 18½ feet. The silt zones (4 to 8) are noncalcareous, while the gravel zone (No. 2) contains limestone pebbles.

In the creek bank just south of a railway bridge in the northwest corner of the southwest quarter of the northeast quarter of section 11, Pilot township, the following section was seen:

		Feet
4.	Gravel, unleached. *Iowan*	4
3.	Clay, dark gray to dark drab, noncalcareous, compact, silty	3
2.	Sand and silty sand, noncalcareous	4
1.	Till, brown, calcareous. *Kansan*	

A few rods farther southeast is a much higher bank, but it was so badly slumped that the section could not be made out. It is Kansan till at the base, overlain at places by one to two feet of coarse ferruginous gravel and then by 12 to 15 feet of noncalcareous brown loesslike clay and silty sand, which apparently is Loveland but all badly slumped and poorly exposed. A grass-covered steep slope rises 15 to 20 feet higher.

In the bank of a tributary of this creek valley from the southeast, just south of the north line of section 14, the following section was exposed:

		Feet
5.	Surface loam, dark yellow	6
4.	Gravel, light colored, calcareous	12
3.	Silts, brownish yellow, with a strongly ferruginous layer at the top	4½
2.	Bowlder zone with a pebble matrix	1
1.	Till. *Nebraskan*	10

Zone 5 is probably surface wash, zone 4 is probably Iowan gravel. Zone 3 is Loveland and the strongly ferruginous layer at its top may represent an old soil zone, or it may be simply a concentration of irony material at the top of a relatively impervious zone.

Near the east line of section 10 in the south bank of the creek is an exposure which was studied in 1910 and again in 1927. At the later date the exposure was as shown in figure 11 but was too irregular for a section. The till at the base is Kansan. The horizontally bedded gravel at the top is Iowan. The irregular unit of gravel, sand, silt and till between cannot be definitely placed. The irregular mass of till at the top of this unit is somewhat lighter in color than the usual Kansan, but this is commonly true of the till associated with gravel.

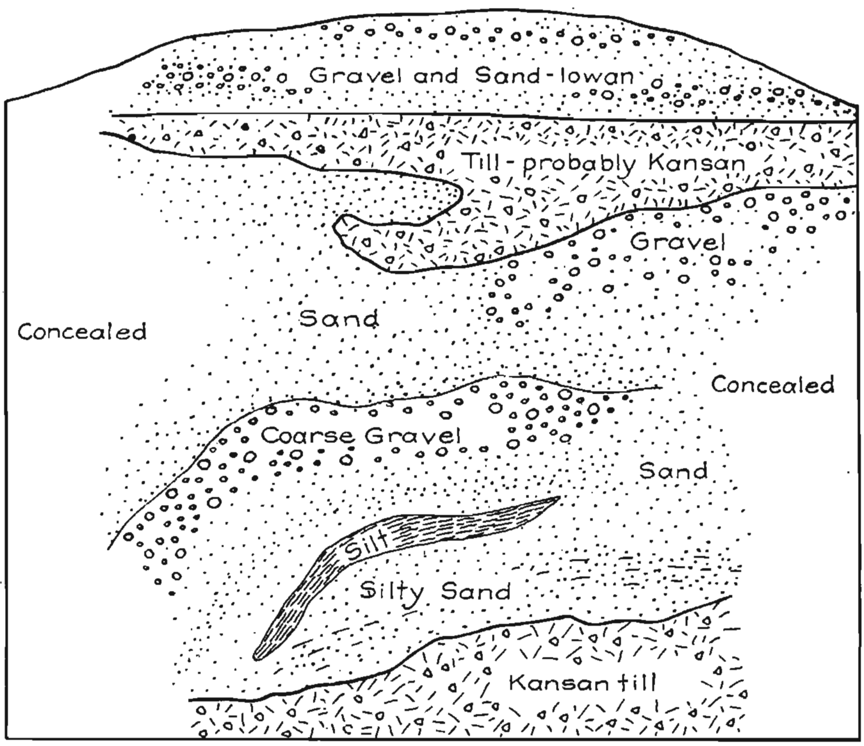

FIG. 11.—Sketch of an exposure in the creek bank near the east line of section 10, Pilot township, Cherokee county, showing a greatly contorted and mixed sand and gravel mass resting on Kansan till and with probable Kansan till above. The horizontally bedded gravel and sand at the top is apparently Iowan.

The irregular character of this unit suggests that a deposit of sand and gravel was plowed by an ice sheet which distorted it and introduced the till at the top. If the upper till is Iowan, then the Iowan ice sheet extended to this place, overrode and distorted the gravel which had probably been deposited just in front of the ice sheet, and introduced the till. If the upper till is interpreted as Kansan, then the Kansan ice sheet plowed up a deposit of gravel which had possibly been formed just in front of the ice sheet and incorporated a mass of it in the Kansan till; or a deposit of gravel within a moulin up in the Kansan ice sheet might have furnished the gravel. If all the till is Kansan, then this mass belongs to the class of included gravel masses to be discussed on pages 111 to 115.

The elevations of the various exposures of unquestioned Nebraskan and

Kansan tills along these creek valleys show that the Kansan drift sheet was laid down on a surface of Nebraskan till which had a relief of at least 50 feet. If the upper till is Iowan, then it was deposited down in a valley 75 to 100 feet deep, cut through the Kansan drift into the horizon of the Nebraskan drift, as shown by the Kansan and Nebraskan exposures on the upper slopes of this valley, one-fourth mile to the north. The writer interprets all the till of this exposure as Kansan and the irregular gravel mass below the upper till as Kansan gravel included in Kansan till.

The next creek valley to the south in section 23 and the northeast part of section 22 has similar deposits. The south slope of this valley in the northeast part of section 22 showed the following section.

		Feet
5.	Gravel and sand in alternating layers, calcareous, with pebbles and some cobbles up to 8 inches in diameter	17
4.	Sand, yellow, calcareous, medium-grained, with coarser layers in upper part and grading downward to fine-grained sand with silty layers	15
3.	Silt, sandy silt and fine sand in alternating layers, calcareous, blue to brown, compact. Some of the silt layers contain snail shells.	17
2.	Sand, coarse, and fine-grained gravel with a layer of bowlders at the base. Material greatly iron-stained, but calcareous and locally cemented. Copious springs issue at the base of this zone.	5
1.	Till, tough, greenish blue, with a very few pebbles. *Nebraskan*	9

The principal silt division (No. 3) is certainly the same as that called Loveland in the valley to the north, but here it is calcareous and also appears to grade through sandy silt and fine sand (No. 4) to the gravel horizon at the top as if the whole belonged to one unit.

About 150 yards southeast of the large exposure just noted, the south bank of the ravine showed the following:

		Feet
3.	Silt, calcareous, and sandy silt, in alternating layers	5
2.	Loesslike clay, blue, calcareous, with many snail shells	5
1.	Gravel, calcareous	4

Farther up this creek valley near the quarter-section line in the north part of section 23 there are several exposures of silts and gravels too badly slumped to yield sections.

In the southeast quarter of the northeast quarter of section 23, about 100 yards west of the road, the north bank of this valley showed the following:

		Feet
6.	Loesslike clay, buff to brown, leached, with a few thin seams of sandy material	6
5.	Silts, calcareous, sandy, with a few pebbles	3
4.	Silts, gray, calcareous, sandy, with a few fossils	5
3.	Gravel and sand, mottled dark brown, calcareous, with some black (MnO_2) staining	5½
2.	Gravel, calcareous, rusty, coarse, with black (MnO_2) staining	3
1.	Silts, dark gray, calcareous, sandy, with carbonaceous material	2

Zone 1 comes down to the base of the exposure at the center, but to the east and the west the Nebraskan till appears from below and rises to a height of about 10 feet in the bank, with the several lower zones of the above section abutting laterally against the till. On the east there is also Kansan above the Nebraskan, but its lateral contact with the silts is concealed. The horizontally bedded silts were evidently laid down in a depression cut through the Kansan into the Nebraskan till.

The interpretation of the silts, tills and gravels of Pilot township has a bearing on the mapping of the Iowan boundary. As noted above the Iowan boundary as traced in the foregoing section would not permit Iowan drainage to enter all of these valleys. A somewhat greater extension of the Iowan region into the east edge of Pilot township would permit Iowan drainage to enter all of these valleys; an extension of the Iowan region to the Little Sioux, southward from Cherokee to the center of Pilot township, would include all the region discussed under this heading. These two alternative boundaries are shown on Plate I.

The topography of northeastern Pilot township shows none of the characteristics of the Iowan drift region. The two exposures of till suggesting Iowan, that near the round-house in southwestern Cherokee (page 71) and that near the east line of section 10, Pilot township (page 74), can both be better interpreted as Kansan. There is, therefore, no basis for an extension of the Iowan region to the Little Sioux valley in central Pilot township.

The silts and silty sands of Pilot township are not a characteristic feature of the Iowan region, but the associated gravels are like those of the Iowan region. However, both types of deposits exist out on the Kansan region beyond the greatest possible extension of the Iowan region. For example, in a small valley tributary to the Little Sioux in the central part of section 6, Silver township, five miles southwest of the exposure in section 22 described above, there is an exposure of about 15 feet of blue-gray silty material with interbedded layers of sand and with some fresh gravel overlying. It is only in the notably greater development of the silts and sands that Pilot township stands out.

Most of the sections described above under this heading show a horizon of fresh gravel at the top, and it is probable that the Iowan ice sheet did cover the divide along the east line of Pilot township southward to section 24 and furnished the drainage which brought in these gravels. These gravels are not well set off from the silts below and in one section (page 76) they appear to grade into each other. It is probable, therefore, that the silts represent only a small part of the entire Loveland, namely that part just preceding the Iowan ice age. In fact, it is possible that the silts of Pilot township were thrown down in the slack waters of the tributary valleys of the Little Sioux, which were ponded by the aggradation of the floor of the major valley by the Iowan outwash gravels which built the high terrace level of the Little Sioux valley. By this interpretation they would be essentially Iowan in age.

Along Maple River Valley.—Southward from southwestern Pitcher township the Maple river valley forms the approximate boundary of the Iowan drift southward for about 12 miles to Galva in northeastern Ida county (Plate I). This again is a generalized boundary as was true along Mill creek valley, and it would not be possible to show that the ice came down to the valley everywhere along this course. Several miles back from the boundary in eastern Pitcher and Diamond townships, and on to the east in Buena Vista county, the Iowan topography is well developed.

A number of kamelike gravel hills are found east of Maple river in southern Pitcher and in Diamond townships, and these aid in giving a constructional appearance to the topography. They have their best development in sections 28 and 33 of Pitcher township and in sections 4 and 35 of Diamond township (page 97).

Besides the gravel hills indicative of Iowan age there are examples of the billowy Iowan topography near the Maple river valley in the northwest quarter of section 21 and the southwest quarter of section 33, Pitcher township, and in section 4, the west part of section 16, the east part of section 28 and the north part of section 34, Diamond township. Pebbly swells appear also on the north line of section 16 and in the northeast quarter of section 28.

In Galva township of Ida county the relief for two to three miles back from Maple river is 50 to 75 feet, and in this greater relief the Iowan topography does not have its typical development. However, in the northeast quarter of section 15 and the southeast quarter of section 10 there is a group of gravel hills, one of which on the section line has an exposure showing a ferruginous, dirty gravel with clay-balls; in the northeast quarter of section 24 there are a dozen or more low swells that show pebbles;

pebbly surfaces were seen in the northwest quarter of section 12, the north half of section 23 and the northwest quarter of section 25; and slightly billowy surfaces suggestive of Iowan drift appear at several places. On the whole, the evidence seems sufficient to justify placing the boundary along the Maple river valley southward to the mouth of a small creek that enters just west of Galva.

Farther eastward the northwestern part of Sac county shows good Iowan drift topography between Early and Schaller and west almost to the county line, where the less typical Iowan noted above begins.

At the northwest corner of section 26, Galva township, just southwest of the village of Galva, a road cut beneath the railway showed, in 1927, leached buff loess 10 feet thick, overlying five feet of sand and fine-grained gravel which is in part leached to a depth of one foot. The exposure is just at the boundary of the Iowan drift area, as mapped, and the sand and gravel look like Iowan material, but the thickness of the overlying loess and the depth of leaching is unusual.

West of Maple river valley in southeastern Cherokee and northern Ida counties an erosional topography on Kansan drift is found. On the slope of the valley it is not very different from the Iowan to the east, but two to three miles to the west the typical Kansan topography appears.

Maple river is bordered by a valley flat one-fourth to one-half mile in width which is in part at least underlain with gravel, but only at a few places do gravel benches appear. The small creek valley of section 23 at Galva carries a gravel deposit and there are low benches on either side of this valley. A pit has been opened in this deposit just north of the town, exposing fresh gravel. The absence of gravel deposits along this portion of Maple river is in contrast with their great development along Mill creek in northern Cherokee county, and the reason for the difference is not evident.

From Maple River to Odebolt.—At the mouth of the small creek west of Galva the Iowan boundary leaves Maple river valley and runs southeast through Silver Creek and Richland townships toward Odebolt (Plate I). Along part of this course through Galva and Silver Creek townships the exact location of the boundary is not definite, and several alternative courses were considered in the field. Farther south in Richland township the boundary is more definite.

Leaving Maple river the boundary is mapped as passing southeast across sections 26, 35 and 36 of Galva township. The southeast corner of Galva township and southwestern Eureka township to the east have a topography apparently erosional, but there are slight constructional features and pebbly swells in the southwest quarter of section 20 and the north part of section 32, Eureka township, and in the northwest quarter of section 25 of Galva township. West of the boundary section 35 and the west part of section 26 have a rolling Kansan topography and the road along the west line of section 26 shows several exposures of loess.

Crossing into Silver Creek township, the boundary runs south across the west part of section 4 and thence southwest across the northwest quarter of section 9 and the southeast quarter of section 8, to the valley of Silver creek in the north part of section 17. On crossing this valley the boundary changes its direction and runs south of east through the central part of section 16 and the south part of section 15, where it again takes the general southeast direction and crosses parts of sections 22, 23, 26 and 25 (Plate I). The projection of the ice to the southwest into section 17 was down the valley of Silver creek, which facilitated the ice motion and allowed it to push farther southwest. The northeastern part of Silver Creek township is moderately rolling, with certain parts showing the billowy Iowan topography, and there are pebbly swells in the northeast quarter of section 3, at the quarter-corner on the north of section 9 and on the slope of the valley in the southwest quarter of section 9 and the southeast quarter of section 8. The western and southern parts of the township are rolling, with a much more definite erosional topography.

West of Maple river valley in southern Galva township and through Logan township there is a region of higher altitude and more rugged topography. West of Galva in sections 27 and 28 this region has a relief of 75 to 100 feet, is very rugged, and has a surface covering of loess. These conditions continue southward through Logan township. From western Silver Creek township, the rugged area across the valley is prominent, rising above the divides on the east, and the contrast between the gentle slopes of the moderately rolling topography on the east and the bold rugged topography on the west is very striking.

In southeastern Logan township the area of rugged loess-covered topography crosses to the east of Maple river valley and covers the point of the upland between Buffalo creek and Maple river. Its north edge crosses sections 25 and 30 and along this line the rugged topography changes abruptly to the gently rolling surface to the north. Exposures along the county line road in the southwest quarter of section 30, Silver Creek township, show 8 to 10 feet of loess without reaching its base. This higher rugged topography continues southeast across the southwest corner of Silver Creek township and across northern Blaine township, occupying the divide between Elk and Odebolt creeks. The decided contrast which comes at the northeast edge of this higher, more rugged area suggests strongly the possibility that the Iowan boundary may lie along this edge.

There is, however, a belt of erosional topography about four miles wide between this area and the better developed Iowan drift topography to the east.

Southeast of the center of Silver Creek township in sections 22 and 26 there is a high, ridgelike area that has characteristics similar to those of the more rugged area to the southwest. It is loess-covered in part, shows till on some of the steeper slopes, and stands well above the surrounding region. The Iowan boundary lies along the east slope of this elevated area through sections 23, 26 and 25.

In the southeast corner of Silver Creek township the boundary approaches Elk creek valley and here there is another slight deflection from the general course. The boundary runs south across section 36 to Elk creek, and thence eastward along the south slope of the valley through the northeast part of section 1, Blaine township, and the central part of section 6 of Richland township, Sac county (Plate I). In the north part of section 8, Richland township, the boundary assumes again the general course east of south and passes through the east part of section 8 and the west part of section 16. Along this course the Kansan and Iowan drift characters are distinct half a mile in either direction from the boundary as mapped. Sections 4 and 9 to the east show Iowan drift topography, while sections 8 and 17 to the west are distinctly erosional. Good contrasting views of the two types may be had from the north line of section 8.

The rugged loess hills noted above as coming southeastward across northern Blaine township cross sections 18 and 20 of Richland township and in the west part of section 21 the Iowan drift boundary lies along the edge of this rugged area, giving a well defined boundary. The contrast of the two topographies is well shown from the high area in the west part of section 21. The view to the east, over central and eastern Richland township, shows a rolling plain with a relief of 20 to 40 feet. The slopes are gentle, the features apparently constructional and the locations of the stream courses rather ill defined. The view to the west shows an eroded region with steep slopes and sharp crests and a relief of 100 to 150 feet. One mile to the southwest is the broad, open valley of Odebolt creek and beyond this the view extends to the high, rugged divide of southern Ida county. This region to the southwest shows the typical Kansan drift topography of southern Iowa which continues on southward beyond the southern boundary of the state.

From Odebolt to the South Line of Sac County.—At Odebolt the boundary turns eastward and runs across the end of the Iowan drift region toward the Wisconsin drift boundary. This part of the boundary is more irregular, being across the front of the ice lobe, normal to the general direction of ice motion, and the pre-Iowan topography caused a lobate margin. By this course from Odebolt to Boyer river, the width of the Iowan drift area is diminished to barely four miles (Plate I). The course is then southward along Boyer river valley for three miles to the Wall Lake outlet. South of the Outlet the width is still further reduced to two miles and a southeastward course soon carries the Iowan boundary beneath the Wisconsin drift.

The Iowan drift area south of Wall Lake outlet is small, comprising an area of only five to six square miles, two miles wide at the south border of the Outlet and narrowing to a point four miles to the southeast. No part of the area is more than a mile from one of the boundaries or from the Outlet. The region is moderately rolling, and, lying between the rugged loess-covered Kansan drift area on the southwest and the slightly rolling Wisconsin drift area on the east, it is distinct from either of them. On the county line on the south of section 34, Viola township, the Wisconsin drift topography borders the rugged loess-covered Kansan drift, and so it continues on southward across Carroll county.

The erosional topography of western and southwestern Richland township continues eastward along the south line of this township and in Wheeler township to the south, thereby cutting across the general southeastward course of the Iowan drift boundary. This boundary passes southward through the east part of section 28, Richland township, and then swinging southeastward, crosses the north part of section 34 through the south part of the town of Odebolt and continues eastward through the central part of section 35.

In northern Wheeler township south of Odebolt there is a high divide region upon which lie some rather level areas about half a mile wide that locally suggest Iowan topography. They are best developed along the divide running diagonally across sections 3, 11 and 13, Wheeler township. The stream courses on the divides are at some places broad and shallow, but in a short distance from their sources the valleys become deeper and the country is more rolling.

A sewer ditch exposure near the east end of the main street of Odebolt showed three feet of mottled, brown loesslike loam overlying six feet of yellowish sand with a few pebbles and small bowlders. The exposure was 100 to 150 feet in length and showed no change laterally and the bottom of the sand horizon was not reached. This sand is just within the boundary of the Iowan drift and probably was washed out from the ice front and deposited in the waters ponded between the edge of the ice and the divide to the south. Five miles south of Odebolt, in sections 26 and 27 of Wheeler township, there are some pits in a gravel deposit in the valley of a southward flowing stream which heads in section 3 just south of Odebolt, and this gravel also may have been deposited by waters from the Iowan ice front, which passed over the divide south of Odebolt and escaped down this valley to Boyer river.

The region just north and northeast of Odebolt for several miles has a well defined Iowan drift topography. The adjoining parts of sections 35, 26 and 25, just east of Odebolt, lie in a broad shallow depression, draining westward, and constitute the most positive case of Iowan drift topography found near the boundary in Sac county. From the central part of section 35, Richland township, the boundary makes a broad curve to the north, passing through the south part of section 25 and the south part of section 30, Clinton township, and in the southwest quarter of section 29 comes into the valley of a small creek, down which it runs for a distance of about two miles to the northeast quarter of section 4, Levey township (Plate I). This northward curve of the boundary is where it crosses the prominent divide area to the west of Boyer river, and farther south, in the northeast quarter of section 31 and the west half of section 32, this divide area becomes prominent and rugged and continues so southeastward across sections 5, 4 and 10 of Levey township. In section 32 and on to the southeast it has a relief of 75 to 100 feet, with very steep slopes and sharp crests, and the road cuts expose 15 to 20 feet of loess, without reaching its base. Across the valley and the boundary, in section 33, the general altitude is 30 to 50 feet lower, the surface is moderately rolling with long, gentle, faintly undulating slopes, and the loess is thin.

In the northeast quarter of section 4, Levey township, the boundary again bends northward, passes around a rugged area in sections 3 and 34, and, running through the west and north parts of section 34, strikes the valley of Boyer river in the northeast corner of this section. Its course is thence southward down the Boyer valley for more than four miles to the Wall Lake outlet. Along this part of the boundary the opposite sides of the Boyer valley present a contrast like that described above.

Clinton township to the north has a relief of 20 to 40 feet and contains some rolling topography and a few gravel hills. The Boyer valley, the dominant feature of the township, appears broad and open in a general view, but closer study shows that it has undulating slopes, apparently constructional. The major parts of Clinton, Boyer Valley and Cook townships present an indefinite type of Iowan drift topography, but parts of Richland township are much more definite.

The south part of Levey township, south of the Outlet, has a rough topography with a relief of 50 to 100 feet, and road cuts show thick loess exposures. This continues northward to the valley of a small creek flowing northwest across the northeast quarter of section 25 and the southwest quarter of section 24. North of this valley, in section 24 and east in section 19 of Viola township, the general altitude and relief is less, the topography is less rugged, although the whole is well drained, and loess cuts are not found. The Iowan boundary passes up this valley through sections 24 and 25 and continues in Viola township diagonally across the south half of section 30, the north half of section 32 and the south-central part of section 33 to the Wisconsin drift boundary, under which it passes in the southeast quarter of section 33 (Plate I). In sections 32 and 33 the boundary follows the base of a slope rising to the higher, rugged area to the south.

INTERBEDDED GRAVEL AND TILL

Exposures showing till interbedded with sand and gravel were seen at a number of places within the Iowan area, especially in northern Cherokee county. The sand and gravel are mostly fresh and the gravel is mostly fine-grained. Coarse sand with pebbles scattered through it is common. Some of it is distinctly bedded and some shows no stratification. Locally the gravel is cemented by a calcareous cement and so forms irregular masses of firm conglomerate; or cementation may affect the whole or part of a stratum over a considerable area. Cementation is more common at the top of the gravel zones than at the base and apparently is more common on the face of an exposure than farther back from it.

Distribution and Description of Exposures

By far the greatest example of the interbedding of gravel and till observed 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 were 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 the 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

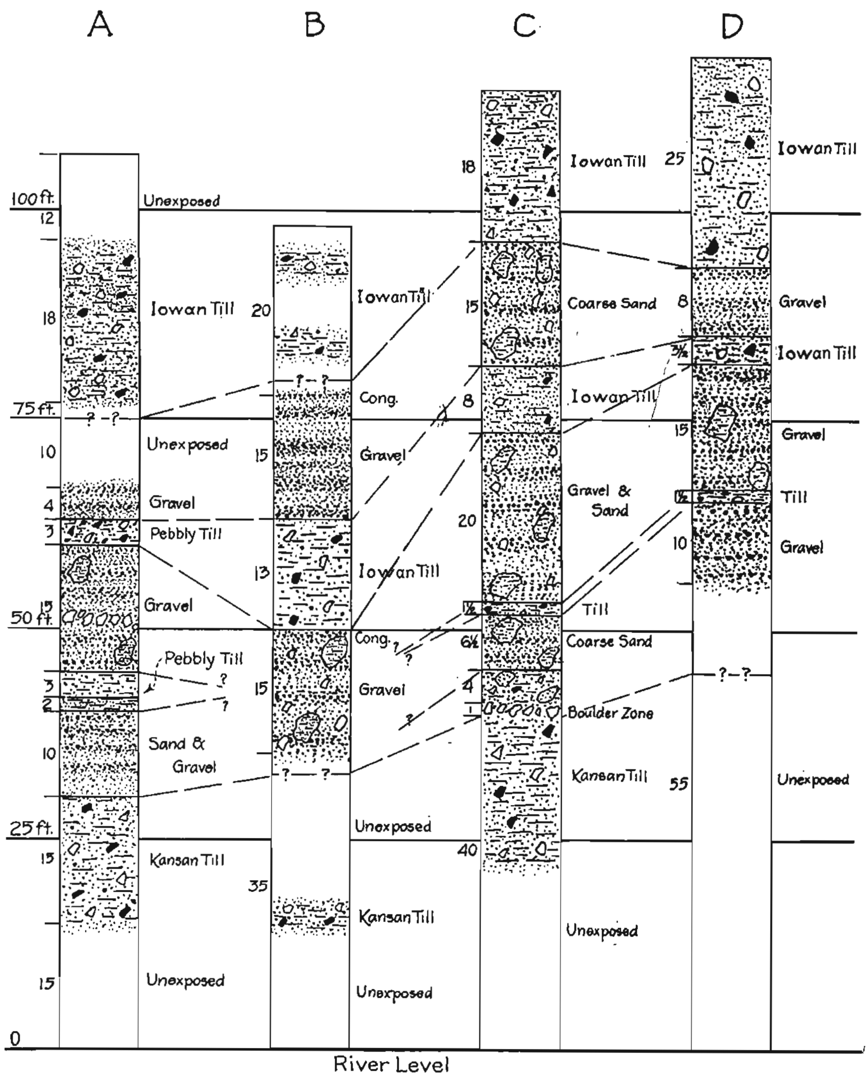

FIG. 12.—Columnar sections of exposures in the east bluff of Mill creek in the west half of section 14, Cherokee township. The probable correlation of the zones of the several sections is indicated.

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 12.

		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
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 bowlders scattered through it and a layer of bowlders 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 elongate 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 three till 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.

		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 of till	15
	In the gully the upper 2 feet of this horizon is cemented, forming a calcareous conglomerate, but this does not continue horizontally beyond the gully. The lower part of the slope is so badly slumped that the lower contact of the gravel could not be exposed.	
1.	Unexposed to creek level, except for one small outcrop of oxidized, brown Kansan till at 15 feet above the creek	35

This section shows two distinct layers of fresh gravel, each at least 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.

		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 bowlders	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.

		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 bowlders. Pink and gray granite of the fine-grained type predominate, but basalts are numerous and limestones are more prominent than is common among bowlders.

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

The banks of the creek valley in section 24 of Cedar township, Cherokee county, east of Larrabee, show a number of small exposures with gravel and sand associated with the till. Examples appear a few rods to the north and to the south of the east-west quarter-section line. None of these exposures is very extensive, and it is not clear whether these gravel zones are within or at the base of the Iowan till. Farther down the creek valley exposures of gravel, sand and silt associated with till may be seen at a number of places. Some of these gravels evidently are included masses, while others may be gravel zones of some extent. A conglomerate ledge projects at one place, and elsewhere masses of conglomerate lie on the surface. The valley slopes are quite completely grassed over, but if good exposures existed the section might be somewhat similar to that of the Mill creek bluffs described above.

At various other places examples of gravel layers interbedded with the till were seen, which indicates that the phenomenon may have a rather general distribution, but nowhere else are the interbedded layers known to be so numerous as in the Mill creek bluffs north of Cherokee.

In the till of northwestern Iowa there is a considerable quantity of gravel and sand in the form of inclosed masses. Many of these masses are in till exposures within the area of Iowan drift, but some are in the area of the Wisconsin drift and some in the Kansan drift region. All these inclosed masses will be treated in the discussion of the Kansan drift region (pages 111 to 115).

Origin

The advance of the edge of an ice sheet probably is really a succession of advances and retreats in which the advances are greater than the retreats. Likewise the general period of retreat of the ice edge may be broken by temporary advances. Between these two general periods there is a longer or shorter time when the oscillations approximately balance each other and the general position of the ice edge remains nearly constant. These oscillations may be due to seasonal changes or to changes taking place over longer periods. Gravel deposited beyond the front of the advancing ice sheet soon may be overridden by the ice and covered with a deposit of till. If now the ice edge withdraws temporarily, gravel may be deposited on top of the till only recently laid down. Readvance of the ice would result in a second till horizon, and so with several oscillations several alternations of till and gravel might be formed. It is not necessary to assume any great oscillations of the ice front, for none of the gravel horizons noted above has been shown to cover any considerable area. An oscillation of a fraction of a mile, or a few miles at most, would be adequate. The greatest known succession of till and gravel horizons, that of the Mill creek bluffs north of Cherokee, is at the edge of the Iowan drift sheet, and it is probable that the greatest and most frequent oscillations would take place at the time of maximum extent of the ice sheet.

Gravel deposited near the edge of the ice, in the way just outlined, would be of the outwash type, consisting of fresh, unweathered material with some pebbles of soft rocks, and would rest on fresh till. The gravel of these horizons is, therefore, interpreted as having been deposited just beyond the front of the ice sheet during the oscillations that took place at the general stage of maximum advance or during the minor oscillations within the stages of advance and retreat.

THE GRAVEL HILLS

At a number of places within the area of the Iowan drift there are mounds composed of gravel and sand. Their slopes are gentle and few of them rise more than 15 to 20 feet above their surroundings. In form they resemble the kames of the Wisconsin drift, though they are much less conspicuous. Some of them are isolated, and some are in groups.

Nature of the Gravel

The gravel of these hills is as a rule fresh or but slightly altered. Some of the exposures, however, show highly oxidized and leached gravel near the surface and a few show an abundance of chalky, calcareous material either as weathered limestone pebbles or as matrix between the pebbles.

As in all types of gravels of our region, gray limestone pebbles predominate to such an extent as to make a light-colored gravel. In twenty-one analyses made in the gravels of this type the limestone pebbles average 55 per cent of the whole. Shale pebbles are present and in certain layers are even abundant. Grains of shale also are abundant in the sand. A characteristic and distinctive feature of these gravel hills is the presence of small rounded masses of glacial clay (clay-balls) among the pebbles. These differ in size from a fraction of an inch to six inches in diameter. They are recorded in nineteen of the twenty-one analyses of gravel from these hills and the average for the twenty-one analyses is 12 per cent. The percentage is 26 or below in all analyses but one, where it is 59. The igneous rock content ranges from 8 per cent to 48 per cent, the lowest percentage being due to the large number of clay-balls. Counting the clay-balls as sedimentary the average total of sedimentary rocks is 76 per cent, and the average total of igneous rocks is 24 per cent. The analyses of pebbles from the gravel hills are tabulated in Table IV, page 175.

The percentage of granite and other igneous pebbles generally is low in comparison with that shown in analyses from gravel deposits of other types. This is due to the large number of clay-balls in these gravels, which by their presence lower the percentage of all other kinds of pebbles. The decrease, however, comes mainly in the igneous pebbles, for the comparison is with gravels that have been more water-worn, and which therefore contain a smaller percentage of pebbles of the softer materials. Chief among these softer pebbles are the clay-balls, which would be destroyed by wear and thus would increase the percentage of all other kinds. But some pebbles of other soft materials would be destroyed by the transportation, so that the increase would be most apparent in the harder types. The increase in the percentage of limestone pebbles due to the destruction of clay-balls apparently was offset by the destruction of some of the softer limestone pebbles, with no apparent gain in limestone.

If these gravel hills are kames or some other type of deposit directly associated with the ice, softer material would naturally be more abundant than in gravels that were subjected to longer transportation and wear. On the other hand, waters flowing well up in an ice sheet, as may be the case with waters forming kames, probably would yield a larger precentage of igneous pebbles than waters draining from the base of the ice.

There is in some cases a great range in the composition of the gravel in the same hill. This is particularly prominent in the case of shale pebbles, for certain layers contain a percentage far above normal, and some layers are made up almost entirely of small grains of shale. In other constituents also there is in some cases a considerable range. No differences were detected that differentiate the deposits of different localities. Analyses from gravel hills a hundred miles apart are as likely to be similar as those from hills near together.

Distribution and Description of the Gravel Hills

Many of the gravel hills of the Iowan drift region are within a few miles of the outer edge of this drift sheet and have been mentioned under the discussion of the Iowan boundary (pages 59 to 84). Some of these may come in for fuller treatment under this heading and others back from the boundary will be considered. The locations of the better developed of these hills, including many of those here discussed, are shown on Plate I by a hollow square.

Northeastern Lyon County.—The northeast corner of Lyon county, north, northwest and west of Little Rock, contains the most conspicuous examples of these hills in the Iowan area (Plate I). Most of them are below the general upland level on the slopes of Little Rock river valley. Most of them rise only 10 to 15 feet above their surroundings, but one in the southeast quarter of section 23 rises 25 feet above its surroundings.

A group of hills just north of Little Rock, near the center of section 26, contained several gravel pits in relatively fresh material. A pit in the high hill in the southeast quarter of section 23 showed 15 feet of coarse gravel and fine sand with many clay-balls, some of which are six to eight inches in diameter. The gravel is unleached but well oxidized and some of the coarse granite and dark igneous pebbles are decomposed. This is a good example of a kamelike hill.

In the southwest quarter of section 27 there are a number of gravel hills with a distinct constructional topography, and one at the southwest corner of the section shows a coarse somewhat rusted gravel in which the coarse-grained igneous pebbles crumble readily. The gravel of this exposure, as well as that of section 26, contains many clay-balls. Other low gravelly hills, without exposures, are found in the west half of section 34 and the east half of section 33.

Southwestern Nobles County, Minnesota.—A large number of gravel hills are found in the southwest part of Adrian, Minnesota, and in the northeast quarter of section 23, half a mile farther southwest. This is within the more hilly belt along the margin of the Iowan drift in Minnesota and the kamelike hills here are larger and more prominent than anywhere to the south in Iowa. A road cut in one of these hills on the north line of the northeast quarter of section 23 showed a great mixture, including coarse dirty gravel with clay-balls; ferruginous bowldery deposits in which many of the dark igneous bowlders are rotten; fine fresh sand; great masses of till; and mixtures of gravel, bowlders and till. The areas north of Little Rock and southwest of Adrian were interpreted by Professor Wilder as parts of the Altamont moraine of Wisconsin age.[31]

Three miles south of Adrian, in the southwest quarter of section 36, West Side township, a pit in a low hill on the north slope of a shallow valley showed in part coarse pebble beds and in part fine gravel and sand. Clay-balls are abundant in the coarser part, one analysis giving 16 per cent. The coarse-grained, dark igneous pebbles crumble easily and most of the limestones are coated brown. In a part of this hill the layers are steeply inclined, and in these layers the laminæ, locally, have an angle of 80 degrees.

Western Osceola County.—In the west part of Osceola county there are low gravel hills on the north slope of a broad, shallow valley in the west part of section 5, West Holman township, and 6 miles south in the southwest quarter of section 5 and the southeast quarter of section 6 of Gilman township. In the hill in southwest 5, Gilman township, a pit exposure showed about three feet of coarse ferruginous gravel resting upon fresher finer-grained material. Clay-balls are very abundant, amounting to 25 per cent of the total contents in one analysis, and on the pit face one was exposed for each square inch of surface.

[31] Iowa Geol. Survey, Vol. X, pp. 132-135, 1900.

Northern O'Brien County.—Gravel hills are found along the headwaters of Floyd river in northern Franklin township of O'Brien county. They are present along a tributary valley in the southwest quarter of section 4, where some gravel pits have been opened, and along the main valley in the southeast quarter of section 4 (Plate I). The exposures seen were shallow and the gravel was strongly oxidized. A low hill just northwest of Sheldon in the central part of section 25, Grant township, Sioux county, is probably a gravel hill.

In a pit in a low mound 3 miles northwest of Hartley, near the center of section 24, Lincoln township, the gravel had been worked out in several places and there was exposed a vertical contact between the gravel mass and the till. This gravel mass, partly inclosed within the till, occupies an intermediate position between the gravel hills and the included masses of gravel. Farther east, in Waterford township of northeastern Clay county, there are several low hills or mounds apparently composed of gravelly material.

Along Willow Creek in Southern O'Brien County.—One of the regions of greatest abundance of the gravel hills is along Willow creek west of Calumet in southern O'Brien county, where more than a dozen of these hills are present in the north parts of sections 22, 21 and 20 and the south parts of section 16 and 17, Liberty township (Plate I). About half of these have exposures showing sand and gravel. The two best exposures are in gravel pits in the north part of section 22 and will be described somewhat in detail.

Near the quarter-section corner on the north of section 22 there is a low mound near the top of the valley slope with a pit 20 to 25 yards across and 10 to 15 feet deep. The material exposed is sand and fine gravel, with some very fine-grained horizons showing extremely fine

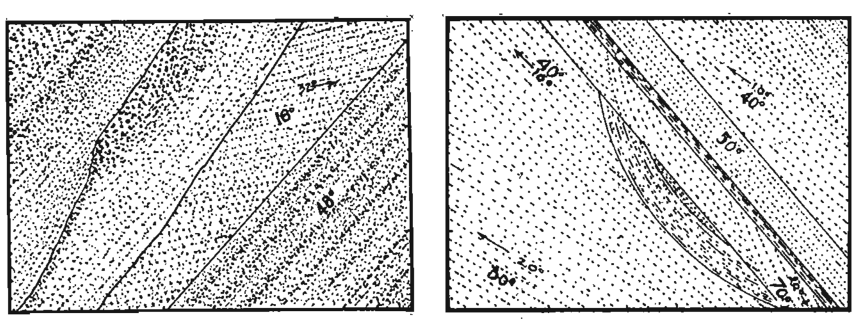

FIG. 13.—Sketches showing cross-bedding and basin structure of sand exposed in a pit in a gravel hill in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county. The present inclination of the beds is given in the more prominent figures. The direction of inclination before the tilting of the gravel mass is indicated by the arrows, and the angle by the less prominent figures. The position of the beds at the time of deposition may be shown by tilting the figure on the left, to the right about 50 degrees, and the figure on the right, to the left the same amount.

lamination. Throughout the lower part of the mass the horizons are inclined, with a strike N. 25°-30° W. and a dip of 45°-50° in a direction south of west. The individual horizons are cross-bedded and laminated. Where the tilting of the mass increased the inclination of the cross-bedding laminæ, these now stand at an angle of 60°-70°. Where the laminæ were originally inclined in the direction opposite to the direction of tilting of the mass, the original inclination was overcome and the laminæ are now inclined 20° to 30° in the opposite direction (figure 13.)

Gray limestone pebbles are by far the most abundant, forming 66 per cent in one analysis. A few shale pebbles appear in all the material but are most abundant in the finer gravel layers, where they form a third to a half of the whole number, and decrease in abundance with the increase in size of the pebbles. Interbedded with these layers containing much shale are other layers of nearly the same coarseness that have only a few shale pebbles.

The following section records the material shown in this pit which dips to the southwest (figure 14).

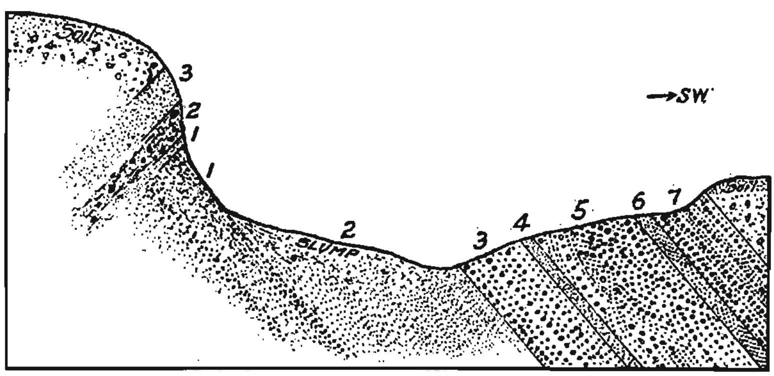

FIG. 14.—Cross section of a pit in a gravel hill in the northwest corner of the northeast quarter of section 22, Liberty township, O'Brien county, showing the structure and the relation of the parts described in the text. The numbers on the figure are the numbers of the zones of the sections recorded in the text.

		FEET
7.	Reddish gravel, fine-grained	4
6.	Sand, very fine-grained, yellowish gray, cross-bedded and finely laminated	1
5.	Sand, coarse, and fine gravel; laminated and cross-bedded in part; coarse gravel and pebbles at base	7½
4.	Sand, fine-grained, cross-bedded	1
3.	Sand and fine gravel; some layers contain much shale	4½
2.	Slumped slope of fine sand	11
1.	Sand, coarse, giving place to fine clayey sand	2

Resting across the edges of the lower horizons of the section just noted and exposed in the east face of the pit are the following:

		Inches
3.	Sand	18
2.	Glacial till	18
1.	Sand	6

These three members have a strike similar to that of the horizons below but dip in the opposite direction (northeast) at an angle of about 50° (figure 14). The till horizon thins to left and right, forming in the pit face a lens-shaped exposure about 15 feet long. It may be either a mass of till put down upon the large gravel mass or the thinning edge of the surrounding till, which appears partly to inclose the gravel mass. If the gravel were entirely worked out the contacts might throw much light on the relation of the gravel masses and the till. Above these three members in the pit face is a jumbled mass of pebbles, bowlders and clay material 3 to 4 feet thick and then a sandy, pebbly soil horizon of 2 feet.

Just south of the northwest corner of section 22 is a large pit in a gravel hill on the south slope of the valley. This is the largest of these hills along this creek and rises 40 feet above the stream, although its top is only slightly higher than the upland just to the south. The material here is somewhat coarser than that in the last pit described. Clay-balls are quite abundant in some zones and average 20 per cent in three analyses. They range in size from small pebbles to masses 6 to 8 inches across. The material is stratified and the horizons are inclined with a strike N. 45°-50° W. and a dip of about 20° SW. The following section is exposed in this pit.

		Feet
10.	Soil, gravelly	1½
9.	Sand and gravel in alternating layers	3
8.	Gravel, coarse-grained, reddish	2½
7.	Sand, fine-grained, cross-bedded	3
6.	Coarse gravel or pebble horizon	15
	Contains numerous clay-balls ranging in diameter from 1 to 8 inches. This horizon is quite variable and at the east end of the pit it contains a 4-foot layer of fine cross-bedded sand, which thins out entirely in 40 feet to the west. At the central part of the pit face it is very bowldery. At the west end it is fine gravel with a few pebble layers.	
5.	Sand, coarse, and fine gravel, poorly exposed. Some of the gravel layers are moderately rusted	15
4.	Sand, fine-grained, with delicate lamination and cross-bedding	1½
	Horizontally this grades into coarse sand not distinguishable from No. 3.	
3.	Sand, cross-bedded, grayish, with a large percentage of grains of shale. Some layers are so largely of shale that they are sticky like clay when moist	2½
2.	Sand, coarse, reddish, cross-bedded, containing clay-balls in upper part. Only partly exposed	8
1.	Sand, fine, yellow-gray, poorly exposed	10

In the north part of section 21 and the south parts of sections 16 and 17, farther down Willow creek valley, there are more of these hills, several of which show shallow exposures of gravel. In the southeast quarter of section 17 a small abandoned pit in one of these hills (figure 15) showed gravel, from which a pebble count was made which contained 59 per cent of clay-balls.

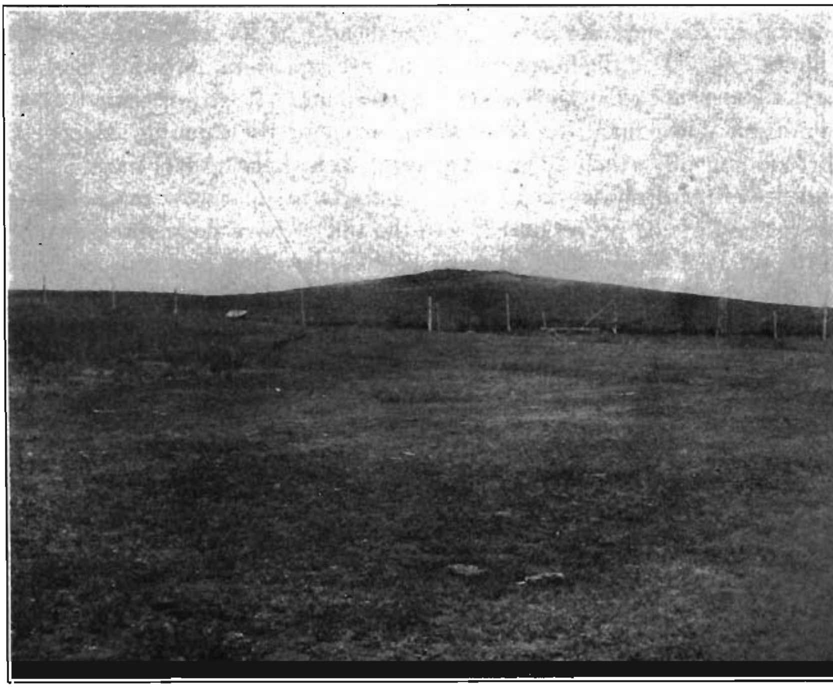

FIG. 15.—View of a gravel hill of the Iowan drift region on the north slope of Willow creek valley in the southeast quarter of section 17, Liberty township, O'Brien county.

Northern Cherokee County.—Near the south line of section 10, Cedar township, Cherokee county, a mile north of Larrabee, there is a gravel hill that has been worked for a number of years. It is located on a divide and stands 10 to 15 feet above its surroundings. Another hill about half a mile to the north is of similar size. A pit exposure in the first hill showed relatively fresh coarse gravel in inclined layers. Clay-balls are plentiful and some are as much as 6 inches in diameter, and the pit face showed a lens of till 5 feet long and 4 to 8 inches thick. This hill was mentioned by Macbride in his report on Cherokee and Buena Vista counties and was interpreted as being "part of a continuous series of such deposits extending from Sibley south and east, including the gravel pit at Sheldon and similar deposits about Calumet."[32] The deposits at Sibley and Sheldon are valley deposits, while the "deposits about Calumet" probably refers to the

32 Iowa Geol. Survey, Vol. XII, p. 322, 1902.

gravel hills along the headwaters of Willow creek, described above. The suggested "continuous series of deposits extending from Sibley south and east" does not exist, although there are several points to suggest such a series.

One mile south of Larrabee, on the east side of the railway, at the center of the northwest quarter of section 26, an abandoned pit in one of these hills showed a rather rusty gravel with many clay-balls. In the north half of the southwest quarter of section 34 are several hills, one of which has an exposure showing the usual light-colored gravel with clay-balls.

Southeastern Cherokee County.—In southeastern Cherokee county there are gravel hills at many places in Pitcher and Diamond townships. They are most numerous along a ridge which extends from the northwest quarter of section 28, Pitcher township, southeast across this section and south through the east part of section 33. Pebbly mounds appear on this ridge just northwest of the center of section 28, in the southwest quarter of section 28, at the northeast corner of section 33, and at a number of places in the east part of section 33. A group of hills near the quarter-corner on the east line of section 33 has been worked for sand for many years. There are other pebbly hills near the center of section 21 and in the northwest quarters of sections 22 and 9. The pebbles, as exposed at the surface of the mounds, show only the hardest varieties of rock, but in the pits and road cuts on the east line of section 33 all the usual kinds of pebbles are present, with some clay-balls. The material in general is more ferruginous than is common farther north, but in the pits just noted there is much fresh fine-grained sand. Gravel hills containing very ferruginous sand appear also in the east part of section 4, Diamond township.

In the northeast quarter of section 35, Diamond township, there is a group of gravel hills which extends also into the adjoining corners of sections 26 and 25 (Plate I). These hills have been extensively used for road material and show a number of poor exposures. At several places the gravel is very rusty and reddish and at places the coarser material is leached to a depth of several feet. Elsewhere it is calcareous to the surface and at no place does the leaching or strong oxidation go to a greater depth than 5 feet, even in the coarser material. One exposure about 100 feet across showed essentially horizontal zones, within which are inclined laminæ and cut-out structures, suggesting deposition in great moulins in the ice rather than as kames at the edge of the ice. In the northeast part of section 25 there is an isolated steep-sided kamelike hill on the south slope of Little Maple river valley.

The great alteration of the gravel of many of the gravel hills of Diamond township raises the question whether they are of the same age as the hills farther north. Their position would make them Iowan, but the material in some of them looks older. However, alteration is not merely a matter of age. The more frequent the alternation of the presence of water and air in the gravel, the more rapid the alteration. Neither water nor air remaining permanently in a deposit will produce much change. The hills of section 35 are in a region of considerable relief where there would be fairly rapid motion of the ground-water and a great fluctuation of the ground-water table with each successive period of rain. Under these conditions oxidation and leaching would be more rapid than in the more level regions farther north.

Ida and Sac Counties.—Gravel hills and pebbly swells exist at several places along the Iowan drift boundary through northeastern Ida and western Sac counties, all of which have been considered sufficiently in connection with the discussion of the Iowan boundary (pages 79 to 84). Farther east, just southeast of Early, in the north-central part of Sac county, only one to three miles from the Wisconsin drift boundary, gravel hills with pit exposures are found in the southwest and northeast quarters of section 10, Boyer Valley township. The material seen in the pit in the southwest corner of the section consists of well oxidized gravel and fresher cross-bedded sand. The coarse-grained igneous pebbles and cobbles and even some of the limestone pebbles are largely decomposed. The surface of the hill on which the water tank is located at Early is pebbly, and 5 miles south of Early a low gravel hill is located just east of the southwest corner of section 34.

In his report on Sac and Ida counties, Macbride mentions gravel deposits in and about Early;[38] gives pit sections from both the gravel hills of section 10; and shows gravel pits on the Sac county map in section 10 southeast of Early and in section 31 west of Lake View. Concerning these gravel deposits, he says they "represent probably an overwash from the drainage of the Wisconsin front". All these hills are well up toward the top of the divide between Boyer river and Indian creek, one to two miles west of the Wisconsin drift margin, which lies along Indian creek valley. Iowan drift topography intervenes between this drift margin and the gravel hills, and there is no evidence that the Wisconsin ice occupied any part of the area west of Indian creek or drained across this divide. The topographic position of the hills and their isolation from the Wisconsin drift margin show that the material was not derived from the Wisconsin ice margin.

One mile north of Wall Lake, in the central part of section 1, Levey township, there is a group of gravel hills, covering 15 to 20 acres, which

38 Iowa Geol. Survey, Vol. XVI, p. 540, 1906.

have been extensively worked for a number of years for road ballast. The material here is light-colored gravel with a high percentage of limestone pebbles and is much fresher than most of the material of the hills south of Cherokee. In one of the pits there is much light yellow siltlike material mixed with the gravel. Gravel hills are present also along the west line of section 1. In Clinton township they are present in the northeast quarter of section 32, the northwest quarter of section 35 and the southwest and northeast quarters of section 26.

A few gravel hills are found in the Iowan drift area south of Wall lake outlet. In the north part of the southwest quarter of section 19, Viola township, a pit on a valley slope exposes a fine gravel with much limestone. Clay-balls are abundant and the material is evidently of the gravel hill type. Gravelly swells are found also near the quarter-corner on the south of this section. In the northeast quarter of the southwest quarter of section 20 there is a gravel pit in a shoulder on the east slope of the valley that forms the Wisconsin drift boundary. The material is a dirty gravel containing many clay-balls and masses of till. This appears to be one of the gravel hills which characterize the Iowan drift region, although the surface just to the east shows Wisconsin drift topography.

The Origin of the Gravel Hills

As to the origin of the gravel hills, four hypotheses will be considered. (1) The hills are kames formed during the retreat of the Iowan ice sheet. (2) They consist of gravel deposited in great moulins or wells in the ice, which, on the melting of the ice, was let down on the drift surface. (3) They consist of masses of pre-Iowan gravel plowed up while in a frozen condition by the Iowan ice sheet and incorporated as gravel bowlders with its debris. When the ice melted these gravel masses were left at or near the surface of the Iowan drift sheet. (4) They consist of masses of gravel plowed up by the Iowan ice sheet and left at the surface of the Iowan drift as in (3), but the gravel is of Iowan age, having been deposited by the waters flowing out from the front of the advancing Iowan ice sheet, which a little later plowed it up.

Before discussing these hypotheses we will summarize some of the evidence which bears upon them.

Evidence of Structure.—Most of the gravel is stratified, and many of the individual layers are themselves beautifully cross-bedded and finely laminated. Most of the deposits that are adequately exposed show the layers inclined at a considerable angle. In the pits just northwest of Calumet the gravel layers have an inclination of 58 degrees, while some of the cross-laminæ are inclined as much as 70 degrees (figure 13). Other masses showing tilted layers are found in section 10, one mile north of Larrabee, and in the southwest quarter of section 36, three miles south of Adrian, Minnesota, where cross-laminæ have an angle of 80 degrees (page 92). These angles are well above the highest possible angle of deposition, and the strata have come into their present position by a tilting of the mass since the deposition of the gravel. The strike and dip of the beds in most cases are uniform in a particular gravel hill, indicating that the tilting affected the gravel mass as a unit.

Evidence of Location.—Most of the gravel hills are located along valleys or on the slopes of valleys. The most notable instance of their location along valleys is along Willow creek, west of Calumet, in southern O'Brien county, but other examples were noted in northern Franklin township of O'Brien county, five miles west of Sibley, and three miles south of Adrian, Minnesota. The pronounced development of these hills north and northwest of Little Rock (page 91) is within or on the slopes of Little Rock river valley. From the valleys these hills may appear prominent, but their tops are seldom higher than the upland; and from the upland they are hardly recognizable. Some of the hills are located on divides, entirely independent of stream courses. No single topographic position will include them all and no hypothesis that hinges upon a topographic association can meet all the necessary conditions.

Evidence of Material.—One of the characteristics of these gravels is the presence of the clay-balls seen in most of the exposures. Balls of clay, even when frozen, cannot be supposed to have withstood the wear of transportation by running water for a very long time, and these clay-balls, therefore, indicate that the material was not carried great distances before deposition. The large percentage of shale and other soft materials found in some of the exposures and the prevalent sub-angular form of the pebbles point to the same conclusion. This evidence is against any hypothesis that would make the gravels interglacial, for interglacial deposits should be of well rounded pebbles and consist of only the harder materials.

The clay composing the clay-balls is typical Iowan till, and therefore the gravel containing them cannot be older than the Iowan ice sheet.

But the gravel containing the clay-balls is at many places partly inclosed in Iowan till, and there seems to be no division between these masses and those completely inclosed in the till and likewise containing clay-balls. The deposit cannot, therefore, be younger than the Iowan ice sheet.

In general appearance these gravels look very much like the gravel masses included in the till, like the gravel interbedded with the till, and like the valley gravels. The pebbles of the gravel are very much like those of the Iowan till, and from its general appearance the gravel might have been derived from this till.

Conclusions.—The first hypothesis listed above (page 99) would make the hills Iowan kames. Kames would be largely on the surface, although their basal parts might go down into the till sheet, as these gravel masses do in most cases. However, the uniformity of dip throughout any one of the hills, the distinctly bedded character of the material, and the well developed lamination and cross-bedding show a regularity too great for kame deposits. Some of the more irregularly arranged and heterogeneous deposits, as that shown in the road cut on the north line of the northeast quarter of section 23, just west of Adrian, Minnesota (page 92), may be kames. The north-south alignment of the hills north of Little Rock might also be explained by assuming that they were built where a stream emerged from the ice, a position which successively changed as the front of the ice retreated.

The second hypothesis assumes that the gravels were deposited in channels, moulins or other cavities, on or in the ice. When the ice melted such masses were left on or in the upper part of the drift sheet, but might extend some distance into the drift or even be inclosed in the upper part. During the lowering of the mass, or during its transportation after formation, it might be tilted in the manner demanded by these hills. 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 it to the ground beneath. It would be relatively easy for masses of till to be incorporated in such deposits by falling from the walls of the channels directly into the accumulating gravel.

The third and fourth hypotheses listed differ only in the time of deposition of the gravel. Both are alike in so far as the method of plowing up the gravel and getting it into the Iowan till is concerned.

The third makes the gravel of pre-Iowan age, the fourth of Iowan age, preceding possibly by only a short interval the time when it was plowed up by the advancing ice sheet. The evidence given above (page 100) is almost conclusive for an Iowan age.

The chief features demanded are that the gravel be of Iowan age; that it be deposited in an approximately horizontal position; that some of the masses be tilted to considerable angle and partly inclosed in Iowan till, but rising slightly above the general surface. Either the second hypothesis, calling for deposition within channels or moulins in the ice, or the fourth hypothesis, with deposition just beyond the front of the ice, will fulfill these conditions, since they differ only in the place of deposition of the gravel. It is probable that the conditions for the development of cross-bedding and lamination of the strata would be better met by deposition just beyond the edge of the ice, but conditions for the inclusion of large masses of till in the gravel are best met by deposition in moulins, from the walls of which the till might fall directly into the accumulating gravels. The writer believes that the majority of the material had its origin in moulins and channels in the ice, as outlined in the second hypothesis, but would not exclude the fourth hypothesis. In so far as the hills fulfill the conditions of true kames, the first hypothesis may be used.

CHAPTER III

THE KANSAN DRIFT REGION

The Kansan drift region of northwestern Iowa is the area which lies west of the Iowan drift boundary. It includes all of Woodbury and Plymouth counties, most of Ida, Cherokee, Sioux and Lyon counties and small parts of Sac and O'Brien counties (Plate I). To the south it broadens out into the great Kansan drift region of southern Iowa and northern Missouri. Northward it continues into southwestern Minnesota and eastern South Dakota, occupying the narrow area between the Iowan drift region on the east and the Dakota lobe of the Wisconsin drift region on the west (figure 2). From the northwest corner of Iowa southward to Canton the Wisconsin drift plain lies just west of the Big Sioux valley. South of Canton the Kansan plain extends westward into southeastern South Dakota and northeastern Nebraska.

TOPOGRAPHY

General Characteristics

The topography of the Kansan drift region is erosional, and the greater part of the area is in the mature stage of the erosion cycle and presents a rolling or rough topography. The entire surface of the Kansan drift is well drained, being characterized by long, direct stream courses, which, for any particular locality, generally have a rather uniform direction but diverge enough to make a dendritic stream pattern. Long, gentle slopes lead down from either side, making a topography of broad, open valleys. Most of the divides are rounded without level upland areas and all the surface is in slopes. The lower parts of the valley slopes are broadly concave and their upper parts are broadly convex. It is the topography typical of maturity. The relief varies from place to place, being only 20 to 40 feet in some places and 125 to 150 feet in others. The steepness of the slopes varies with the relief.

The Kansan drift plain includes considerable range in both relief and degree of dissection. There are a few quite level or almost flat areas; there are areas with slight relief, with long, gentle slopes; areas of moderate relief, well drained; rolling and rough areas with steep slopes; and sharply dissected areas with very steep slopes. These various types of topography have an orderly arrangement with respect to the chief drainage lines and in most cases grade rather gradually from one type to another.

Description of the Topography

The most typical Kansan topography as judged by the standards of southern Iowa is found in the southwest part of our region in Woodbury, Ida, southwestern Sac and western Plymouth counties. Here the relief is 100 to 150 feet and the region is rolling to rough, the typical Kansan of southern Iowa. To the east and northeast, with increasing distance from the great drainage lines, the relief and ruggedness decrease, with prongs of the more rugged topography extending northeast along the drainage lines and prongs of the more even type extending southwest along the interstream areas.

Most of the Kansan region of northwestern Iowa has a rolling topography with a relief of 50 to 100 feet. This type covers Lyon, Sioux, eastern Plymouth and western Cherokee counties. The drainage pattern is distinctly dendritic, the slopes are definite but of moderate steepness, and the region is well drained. This area includes the best farm land of northwestern Iowa.

At several places within this rolling Kansan drift region there are areas that have only slight relief. Several of the more prominent of these lie just outside the Iowan drift boundary and have been mentioned in connection with that subject. There are small areas of this type on the divide south of Odebolt in southwestern Sac county and on the divide around Holstein in northern Ida county. Parts of Marcus township of northwestern Cherokee county are only slightly rolling, and farther northward along this divide between Mill creek and Floyd river there is a considerable area of almost level surface in Caledonia and Baker townships of southwestern O'Brien county. Another quite level area lies in northern Sheridan township of Sioux county (page 65). These more level areas do not seem to represent the original Kansan plain as do the level uplands of southern Iowa, but the whole region seems rather to have been eroded beyond the mature stage of the cycle. It is this more even or slightly rolling type that exists along most of the Iowan boundary, and the Iowan drift region is apparently merely this slightly rolling Kansan type veneered by a thin layer of Iowan drift.

Although erosional features are the dominant ones of the Kansan drift region, there is one region with a topography that is in part constructional. This is a belt five to ten miles wide just east of the Missouri river valley through Woodbury and southwestern Plymouth counties. The topography is of a bold rugged type, characterized by steep slopes which are at many places almost bare of vegetation, by pointed hills, and by narrow ridges (figure 16, page 117). This area has a thick deposit of loess and the topography is partly loess-formed. It continues southward along Missouri river through western Iowa and has its best development south of our region. Five to ten miles from the Missouri and Big Sioux river flats, with decrease in thickness of the loess, this topography grades into the more typical erosional topography of the Kansan drift region.

East of the region which has the distinctive loess topography, the loess is much more extensive as a thinner deposit, mantling the rounded profiles of the drift surface but not notably affecting the topography. This mantling loess deposit, thinning eastward, covers the entire Kansan area.

THE KANSAN DRIFT

General Characteristics

The Kansan till of northwestern Iowa consists of a clay matrix with numerous sand grains, pebbles and bowlders scattered through it. The matrix is finely ground rock-flour, gritty from the presence of very small sand grains, but somewhat plastic if moderately moist. At the surface and in exposures of moderate depth the till is oxidized and has a yellow or brownish yellow color. Below this is the unoxidized "blue clay" phase of the Kansan. The till is cut by numerous joint planes belonging to sets that intersect at such angles as to give the clay a very characteristic fracture into angular fragments a quarter to three-quarters of an inch across. Both the oxidized and unoxidized phases are strongly calcareous, even up to the surface or up to the base of the overlying loess. Calcareous material is present further in the form of small grains, pebbles and cobbles of limestone, and, near the surface at many places, as small concretions and gray powdery material along joints.

The oxidized yellow clay at the surface and on the face of cuts is moderately loose, but a few inches beneath the surface it is compact and hard and if wet is tough and gummy. The oxidized yellow clay horizon has a usual thickness of 15 to 20 feet, with a range from zero to probably 40 feet. In general it is thicker in those parts having a more rugged topography and thinner in the more level regions. It is thicker on the hills than in the valleys, and in some of the marshy flats it is entirely absent and blue clay lies directly beneath the soil or alluvium.

Calcareous concretions one to two inches across exist in the upper part of the oxidized Kansan till in many of the exposures. They are not so large as those of the Nebraskan till but are larger than those commonly found in the loess. They are formed by the leaching of calcium carbonate from the till or the overlying loess and its concentration in nodules lower down. At a number of places these nodules have an elongate form and stand in a vertical position along the joint planes. They are more numerous and larger in the Kansan till south of our region, as exposed in the cuts of the Chicago, Milwaukee, St. Paul and Pacific railway in Carroll county.

In most exposures the blue clay is plastic and gummy and, if only recently exposed, is very tough and hard. When dry it has a light blue-black or bluish gray color on the face of the exposure, while just beneath the surface it is almost black and with greater depth grades into the typical blue clay. The blue clay is exposed in the banks or beds of many valleys where erosion is now active, and is penetrated by all wells of any great depth. Its thickness differs with the total thickness of the Kansan.

The blue clay is the fresh unoxidized phase of the Kansan till, and the yellow clay is the oxidized form. The transition from the blue to the yellow is, as a rule, abrupt or accomplished within a very thin transition zone, but the alteration to a yellow color may extend down into the blue clay along joint planes, affecting the clay for several inches from these planes. Where the till is much broken by intersecting joints and is mixed with irregular pockets and veins of sand which allow the weathering agents irregular access to the till, there is, at the contact, a zone several feet thick made up of masses of unoxidized till enclosed in oxidized till. Where the till is moist and where, because of recent erosion and exposure, rapid alteration is now in progress, a blue-black phase is present in the transition zone between the blue and brownish yellow phases.

Gray limestone is the dominant rock material among the pebbles of the Kansan till, forming more than 70 per cent of the total number of pebbles. Other types of limestones and a few quartzites and shale pebbles increase the number of sedimentary pebbles to about 75 per cent of the whole. The remaining 25 per cent consists of igneous pebbles, chiefly granites. The large cobbles and bowlders are dominantly igneous; quartzite, which is never abundant in the analyses of pebbles, is common; while limestone bowlders are rare. The pebbles of the Kansan drift are in most cases rounded or subangular, but a few are angular. The drift separates cleanly from the pebbles, and the white limestone pebbles show plainly against the darker clay.

Source of Material for the Drift

The bedrock of northwestern Iowa belongs to the Cretaceous system, which also is present in great thickness to the north. The dominant rock of this system is shale, and the remainder is largely shaly limestone and friable sandstone. Its most notable contribution to the drift was the material for the clay matrix, derived largely from the shale, but it also yielded much soft limestone which was ground to powder. Although they contributed the bulk of the drift material, the Cretaceous rocks are not common among the pebbles and never appear among the bowlders.

The compact gray limestone pebbles of the till are commonly unfossiliferous, but a few contain fragments of Ordovician fossils. No limestone of this age is known in the bedrock of northwestern Iowa or for several hundred miles to the north along the course followed by the ice, but in the northwest corner of Minnesota and extending northward along the valley of Red River of the North through Manitoba to Lake Winnipeg and beyond, there is a belt of Ordovician, Silurian and Devonian rocks which probably furnished the limestone pebbles of our region. The igneous pebbles and bowlders were derived from the pre-Cambrian rocks of Canada and northern Minnesota and from the smaller areas in the Red river and Minnesota river valleys. The large amount of calcareous material in the matrix of the drift was derived in part from the impure limestone and calcareous shale of the Cretaceous and in part from the Paleozoic formations that furnished the limestone pebbles.

In the extreme northwest corner of Iowa are a few outcrops of quartzite, and to the northwest around Sioux Falls there are considerable areas of this rock. It is very resistant and furnished many bowlders for the drift of northwestern Iowa. In decreasing abundance they occur southward to the limit of glaciation. The largest of these quartzite bowlders exposed at the surface in our region is "Pilot Rock" in the southeast quarter of section 15, Pilot township, Cherokee county, four miles south of Cherokee. Here is a great block of reddish quartzite about 35 feet by 25 feet and rising 10 to 15 feet above the surface.

Preceding the Kansan epoch, northwestern Iowa had been glaciated by the Nebraskan ice sheet, which deposited a thick sheet of till. As the Kansan ice sheet advanced over the surface of the Nebraskan till, it gathered up great quantities of the older till and mixed it with such new materials as it brought in, making the Kansan drift. It also picked up masses of Nebraskan till and incorporated them in the Kansan till without intimate mixing. There are also masses of gravel, sand and silt inclosed in the Kansan, and these probably were gathered in a similar way either from interglacial deposits resting on the Nebraskan or from outwash deposits laid down in front of the advancing Kansan ice sheet. These gravel masses and the evidence as to their age are considered on pages 111 to 115.

HISTORY OF THE KANSAN DRIFT REGION

A notable characteristic of the Kansan till of northwestern Iowa is the small amount of alteration and weathering which it shows. Oxidation to a yellow color commonly extends to a depth of 15 to 20 feet, and locally the till is iron stained along the joints, but the degree of this oxidation is only moderate. Excessive oxidation of the type represented by the iron-stained horizon (ferretto) present at the top of the Kansan till at many places farther south is lacking in northwestern Iowa. Further, the Kansan till of northwestern Iowa is commonly calcareous to the surface. In only a few places in the south and southwest part of the region was any leached till found. Even where the overlying loess is leached for its entire thickness, the till beneath is commonly unleached. In southern Iowa leached till is commonly present and in many places has a depth of several feet.

In the Kansan drift region of southern Iowa the principal divides of a region commonly rise to a uniform altitude and have some level surface at their summits. These level areas are interpreted as remnants of the original Kansan drift plain, which is thought to have been relatively level without marked constructional features.

These level uplands of southern Iowa are covered with about 10 feet of gray to dark colored noncalcareous sticky clay which Doctor Kay has named gumbotil[34] and interpreted to be the result, chiefly, of the chemical weathering of Kansan drift[35] on the level Kansan drift plain. The characteristics and distribution of the Kansan gumbotil are fully treated in a report by Kay and Apfel in a recent volume of the Iowa Geological Survey.[36] Beneath the gumbotil there is a zone of leached Kansan till about 5 feet thick. This leached zone grades upward into the gumbotil and downward into unleached till and represents a less altered phase of the till. After the development of the gumbotil zone an uplift is believed to have occurred, and erosion has carved out a mature topography and reduced most of the surface below the level of the former gumbotil plain. The above interpretation is based on the evidence of the remnants of this plain.

Remnants of the gumbotil zone are numerous in southern Iowa and continue northward to Carroll and Crawford counties, just south of our region.[37] The most northerly known exposure of the Kansan gumbotil is in a railway cut two miles east of Kiron, a few miles south of the southwest corner of Sac county.

Neither the level uplands nor the gumbotil have been found within our region, although exposures of unleached till have been seen on most of the high areas. However, it is believed that northwestern Iowa has passed through essentially the same history as has been outlined for southern Iowa by Kay. That is, that the Kansan ice sheet left a relatively even drift plain; that the gumbotil and the leached zone below were developed over the entire region; that the gumbotil plain was uplifted; and that it has since been eroded. This erosion, however, has been greater in northwestern Iowa than in southern Iowa, so that, although remnants of the plain and the gumbotil remain in southern Iowa, in northwestern Iowa all the surface has been reduced below the level of the gumbotil plain and every remnant of the plain, the gumbotil and the leached zone has been destroyed.

[34] Kay, G. F., Gumbotil, a New Term in Pleistocene Geology: Science, Vol. XLIV, pp. 637-638, 1916. Also Iowa Geol. Survey, Vol. XXVI, pp. 216-218, 1917.

[35] Kay, G. F., Bull. Geol. Soc. of Amer., Vol. 27, pp. 115-117, 1916. Also Iowa Geol. Survey, Vol. XXV, pp. 612-615, 1916.
Kay, G. F., and Pearce, J. N., The Origin of Gumbotil: Jour. of Geol., Vol. XXVIII, pp. 89-125, 1920.

[36] Kay, G. F., and Apfel, E. T., The Pre-Illinoian Pleistocene Geology of Iowa: Iowa Geol. Survey, Vol. XXXIV, Chapters VI and VII, 1929.

[37] Kay, G. F., and Apfel, E. T., Iowa Geol. Survey, Vol. XXXIV, p. 129, Fig. 27, 1929.
Kay, G. F., Pleistocene Deposits between Manilla in Crawford County and Coon Rapids in Carroll County: Iowa Geol. Survey, Vol. XXVI, pp. 213 to 231, 1917.
Lees, James H., Geology of Crawford County: Iowa Geol. Survey, Vol. XXXII, pp. 322, 323, 1927.

Concerning this matter of erosion of the gumbotil plain in Carroll county just to the south of our area Kay wrote as follows:[38]

"The history of northern Carroll county and farther to the north seems to have differed from the history of the Templeton region (southern Carroll county) in having undergone still greater erosion. Northward from Templeton there are fewer and fewer remnants of the weathered zones until none are found. Moreover, in the region of Templeton there appears to have been more erosion than farther to the south. In south-central Iowa the uneroded remnants of upland with gumbotil and leached drift are a somewhat distinctive feature of the topography."

The above explanation includes several points that have not been conclusively proved, but the interpretation explains the conditions fairly well. It has not been proved that the gumbotil plain extended over northwestern Iowa. However, the writer has seen a good deal of the evidence in southern Iowa and in Carroll and Crawford counties just south of our region, upon which Kay bases the gumbotil interpretation, and considers it so strong that he cannot fail to use this interpretation for the southern part of the region here under discussion. It is believed that the development of the gumbotil to a depth of 10 to 15 feet over southern Iowa required a very great length of time. Such thicknesses are found northward to Carroll county, where a section recorded by Kay from a railway cut three miles west of Templeton shows 15 feet of Kansan gumbotil.[39] A deposit of this origin and representing such a great lapse of time could not terminate abruptly and, therefore, it seems very probable that the gumbotil was developed farther northward over northwestern Iowa during this same long interval of time.

The way in which the remnants of the gumbotil on the highest divides become fewer and smaller as they are traced northward in west-central Iowa, and especially in Carroll county, indicates strongly that these remnants have been entirely destroyed farther north; that is, that northwestern Iowa has been entirely reduced below the level of the gumbotil plain. The unleached Kansan drift at the surface in northwestern Iowa is similar in all respects to the unleached Kansan drift which exists beneath the leached drift and gumbotil farther south. The altitude of the remnants of the gumbotil along the divide between the Mississippi and Missouri rivers increases gradually northward from

[38] Iowa Geol. Survey, Vol. XXVI, p. 218, 1917.
[39] Iowa Geol. Survey, Vol. XXXIV, p. 226, 1929.

about 1,200 feet at Tingley, near the south line of the state, to nearly 1,500 feet west of Templeton in Carroll county.[40] If these altitudes are used to project the plain northward, it is found that it would pass above all the high points of northwestern Iowa.

An uplift of the region is postulated in order to allow the dissection of the gumbotil plain. In southern Iowa, where remnants of the gumbotil plain exist, the postulated uplift rests on firmer basis than in northwestern Iowa, where the uplift is merely inferred. The question as to why northwestern Iowa was eroded more deeply than southern Iowa, in spite of the fact that it is farther up the Missouri valley, has not been satisfactorily answered. Possibly the uplift in northwestern Iowa was greater than in southern Iowa; possibly it occurred earlier. There exist in northwestern Iowa considerable areas of slight relief which by this hypothesis must be interpreted as having been reduced below the original plain, and yet they are not at flood-plain level. The origin of these areas is not understood.

The writer has attempted in earlier manuscripts to develop an explanation of the unleached Kansan drift of northwestern Iowa as compared with the Kansan drift farther south on the basis of difference in the composition of the drift; difference in topography and relief, as affecting the rate of alterations; difference in rainfall and other climatic factors. None of these attempts has been satisfactory. The chief difficulty has been to explain the apparent abrupt dropping out of the gumbotil and leached zone horizons just south of our region. By all these interpretations these horizons should pass out gradually northward or grade into some other alteration product.

GRAVEL AND SAND MASSES INCLUDED IN THE TILL

General Characteristics

There is in the till of northwestern Iowa a large quantity of gravel and sand in the form of inclosed masses (gravel bowlders). These 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

[40] Iowa Geol. Survey, Vol. XXXIV, p. 261, 1929. Also Vol. XXVI, p. 229, 1917.

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 1½ miles south of Washta, is about 35 feet by 20 feet on the face of the cut and another in a Chicago & North Western 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 as 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 for 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 bowlder, but in a few cases a thin shell, concentric with the border, is stained, altered, and partly cemented with ferruginous material. Also in a few cases the gravel is cemented in a shell around the outside of the mass. This alteration and cementation is a contact phenomenon which has been produced since the inclusion of the gravel mass.

Description of Some Typical Gravel Masses

Little Sioux river valley across northern Buena Vista and southern Clay counties has been cut deeply into the till, and both natural and artificial exposures along the valley show many gravel bowlders. 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 North Western railway just east of Sioux Rapids has been noted above (page 112), and gravel masses are numerous in several cuts a little farther east. In the southeast quarter of section 3, Barnes township, Buena Vista county, just east of where the railway crosses the terrace area, is a cut which, although old and slumped, showed a great number of sand bowlders.

Near the top of the bluff north of the schoolhouse at Peterson there is a pit excavation 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, Brooke 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 6 to 8 feet above the ravine bed just north of the exposure. There is little doubt that this is a great gravel mass included in the Kansan till. The bedding of the mass dips slightly to the south and apparently back into the bank to the west. Ferruginous concretionary cementation has affected part of the sand and has formed irregular shaped masses, some of which are more than a foot across. The material composing this mass is much more decomposed and altered than is common for the gravel masses.

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

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 of 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 bluff of Mill creek between the bridges in the northeast quarter of section 23, Cherokee township; in the bluffs of the creek valley of section 24, Cedar township; along the creek valley through sections 11 and 10, Pilot township, south of Cherokee; and at many other places throughout the area. In fact, most large exposures of till show some of these gravel masses. 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 the 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.

Masses of gravel inclosed in Kansan and Nebraskan till are present at many places in western and southern Iowa south of our region. Great masses of gravel, formerly interpreted as Aftonian gravels, in Union county in southern Iowa and in Harrison and Monona counties in western Iowa, have been recently interpreted by Kay as lenses and irregularly shaped masses inclosed within the till.[41]

The Origin of the Sand and Gravel Bowlders

The presence of the rounded, rectangular or angular masses of stratified gravel, sand and silt completely inclosed in the till has been noted. It has also been noted that some of these gravel masses have angular corners projecting into the till and that the layers of the masses have various positions. These points indicate that the gravel masses are fragments of larger deposits which were broken up, probably while they were in a frozen condition, and the fragments were incorporated like rock bowlders in the till. As to the origin and age of the gravel deposit that was thus broken up, two hypotheses may be considered. (1) It was an interglacial deposit which existed in the region prior to the Kansan or Iowan ice epoch. (2) It was an outwash deposit laid down in front of the advancing Kansan or Iowan ice sheet, which a little later plowed it up.

An interglacial deposit should consist largely of well worn pebbles of the harder, more resistant types of rock that are left after the weaker ones have been worn out or decomposed. It would commonly consist of leached material. By both of these criteria the gravel of these masses does not seem to be interglacial.

In general appearance and freshness the pebbles of the gravel masses bear a close resemblance to pebbles picked directly from the Kansan or Iowan till. The clay-ball pebbles which are present in the gravel show that the material was not transported far before its deposition. These clay-balls are of Kansan or Iowan till.

The gravel masses are, therefore, considered to be contemporaneous with the till sheet which incloses them and the gravel is interpreted as having been deposited beyond the front of the advancing ice sheet, which a little later plowed it up and incorporated fragments of the frozen mass in its drift. Deposition in openings beneath the ice or low enough in the ice to become inclosed in the till would also suffice.

41 Iowa Geol. Survey, Vol. XXXIV, pp. 184-195.

CHAPTER IV

THE LOESS

General Characteristics and Distribution

The Kansan and Iowan drift regions of northwestern Iowa are covered with a mantle of fine-grained yellow clay known as loess. In the southwestern part of the area the loess has a considerable thickness, but it thins to the northeast until it is almost negligible. It crosses from the Kansan region east onto the Iowan area and continues to the Wisconsin boundary. In the regions where the loess is thick, it is commonly calcareous to the surface and in many exposures contains calcareous concretions and snail shells. Farther northeast, where the surface is more even and the loess is thinner, it is leached in its upper part, or possibly for its entire thickness, and shells and calcareous concretions are absent.

The Region of Thick Loess

The region within which the loess covering is thick includes Woodbury county, Ida county except the northeast part, the southwest part of Sac county, and a belt along the east side of the Big Sioux valley narrowing northward through western Plymouth, Sioux and Lyon counties. Within this area many road cuts on the slopes or on the crests of the hills expose 10 to 20 feet of loess. It is buff to yellow in color, commonly calcareous to the surface, contains concretions at many places, and in some places is fossiliferous with snail shells. In the more recent road cuts the loess stands as cliffs.

The greatest thickness of the loess is found in a rugged belt five to ten miles wide just east of the Missouri river valley in Woodbury and southwestern Plymouth counties. Here exposures of 30 to 50 feet or more of loess exist. The topography is rugged, made up of narrow ridges and pointed hills (figure 16). The slopes are steep and at many places almost bare of vegetation. The more prominent characteristics of this topography and much of the relief were produced by the deposition of the loess. The elevations of the hilltops of this belt are, in general, greater than in the region to the east. It is an area of distinc-

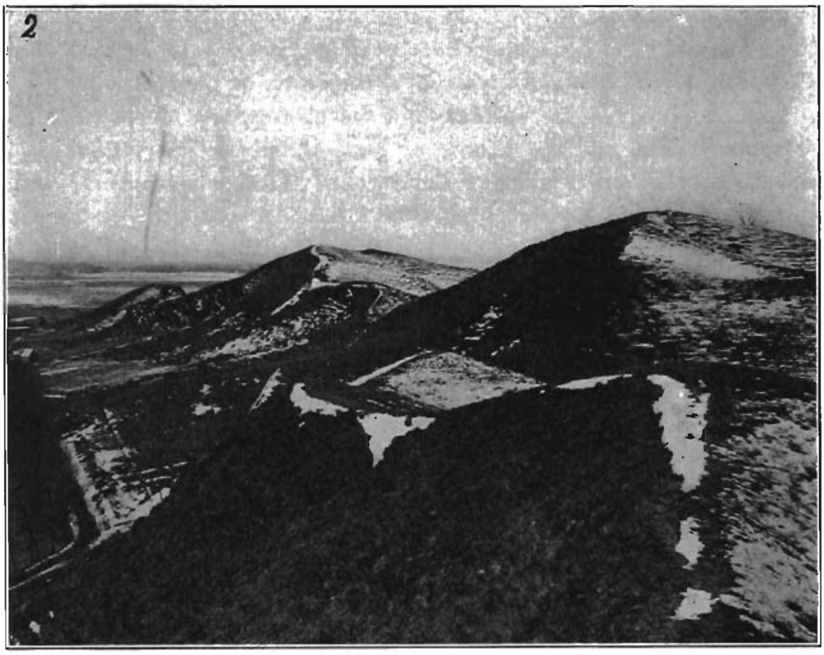

FIG. 16.—The topography of the loess-covered region north of Turin, Monona county. Snow partly covers the surface, especially to the lee, east, of the crests. (Shimek, Iowa Geological Survey, volume XX, p. 289.)

tively loess-formed topography which continues southward along Missouri river across western Iowa.

The Northeast Border of the Thick Loess

Along a belt on the northeast, the loess thins abruptly within a distance of a mile or less, so that there appears to be a loess boundary. This belt, within which the loess becomes so much thinner, leaves the Wisconsin drift boundary near the south line of Sac county and extends northwest across southwestern Sac, northeastern Ida, southwestern Cherokee and southeastern Plymouth counties. West of the Floyd river valley it extends west of north through western Plymouth, Sioux and Lyon counties. The change is more abrupt in Sac and Ida counties than farther northwest and more abrupt where this belt follows valleys than where it crosses upland country. In some places it seems to be a definite boundary, but on the whole it is simply a zone within which the thinning of the loess is very marked.

The zone within which the loess thins so notably is quite definite south of Wall Lake in Sac county through sections 33, 32 and 30 of Viola township and sections 25 and 24 of Levey township. This is along the Iowan boundary. To the southwest is rough, Kansan topography with a relief of 50 to 100 feet and road cuts at the crests of the hills show 10 feet or more of loess. To the northeast the Iowan region is much less rugged, the relief is less, and the mantle of loess is only a few feet thick. A marked contrast exists along a small valley through sections 33 and 32 of Clinton township, northwest of Wall Lake. In section 32 on the southwest of this valley the topography is rugged with a relief of 75 to 100 feet, with very steep slopes and sharp crests, and the road cuts through these crests expose 15 to 20 feet of loess without reaching its base. Across the valley in section 33, the general altitude is 30 to 50 feet lower, the surface is moderately rolling, and loess is not prominent. A similar contrast exists along the Boyer valley in sections 34 of Clinton and 2 of Levey townships. In both of these cases the Iowan drift boundary is also the boundary of the thick loess.

Northwest of Odebolt, toward Maple river, there are several places where the border of the thicker loess is definite, but it is not a continuous boundary. The loess is thickest on the higher points and there is commonly some group of hills or a divide where the thicker loess projects farther northeast than is general, and along the northeast base of these hills the marked change is located. The first course of this type northwest of Odebolt is along the northeast base of a belt of hills in sections 21, 20 and 18, Richland township. The base of this ridge at its east end is the Iowan boundary, but the boundary thence runs on north and does not continue along the northeast face of the ridge. This belt of loess-covered hills continues on west through Blain township, Ida county, as the divide between Odebolt and Elk creeks. Some hills with thick loess, however, exist on the divide north of Elk creek in the southwest corner of Silver Creek township and in southeastern Logan township in the angle between Buffalo creek and Maple river, where a very marked contrast exists for a short distance.

A very marked contrast exists along the course of Maple river valley from section 25 of Logan township, Ida county, north to section 22 of Galva township. Rugged topography with deep loess cuts exists to the west of the valley, while to the east it is less rugged and there are few exposures of loess.

At the south end of the Iowan drift region southeast of Odebolt there is a close co-ordination between the Iowan boundary and the edge of the thick loess deposit and it appears that the thick loess was deposited while the Iowan ice sheet protected the area on the northeast.

Northwest of Odebolt through northeastern Ida county these boundaries are not the same, the Iowan boundary as mapped being east of the edge of the thick loess. At Galva the Iowan boundary comes to the east side of Maple river valley, while thick loess covers the region west of the river. North of Galva there is no further relation between the two boundaries. The Iowan boundary runs north-northwest across Cherokee and O'Brien counties. The edge of the thick loess runs west-northwest across northern Ida, southwestern Cherokee and southern Plymouth counties. Westward the transition belt becomes broader and less definite and can hardly be considered a boundary.

At a number of places along the north-south valleys more rugged topography exists and the loess is thicker on the west slope than on the east. This feature is present in the case of several of the parallel valleys and is not a characteristic simply of the belt within which the loess becomes thinner but of the region of thick loess. This feature is shown along the West Floyd and other valleys of west central Plymouth county.

The Region with Loess of Medium Thickness

Over eastern Plymouth, western Cherokee, most of Sioux and western Lyon counties the Kansan drift region is rolling and the loess has a moderate thickness of five to fifteen feet. The relief varies from place to place, in general becoming more even to the north and the east. The preloess topography was rolling with similar features and relief and the deposition of the loess had little effect upon the topography. It is a loess-mantled topography. Roadside exposures of the loess are numerous along graded roads, the loess being commonly thicker on the slopes than on the crests of the ridges. On the more level surfaces the loess is leached for one to three feet, but on the steeper slopes where erosion is active it is commonly calcareous to the surface.

The Region of Thin Loess

The loess continues to thin to the east and northeast, decreasing to a mantle of two to five feet. This condition exists over the eastern part of the Kansan drift region in central Cherokee, southwestern O'Brien, eastern Sioux and eastern Lyon counties and over all of the Iowan drift region east to the Wisconsin boundary. Most of this region is quite even, and exposures over the uplands are few and shallow. The natural exposures, being on the lower slopes of the valleys, do not commonly show the loess, which has been removed from such positions, and one must depend largely on artificial exposures on the level surfaces for data as to its thickness.

Within this region the loess is leached in its upper part and at many places for its entire thickness, where this is less than five feet. Where the loess is thicker than four to five feet, the basal part is unleached. The underlying till is commonly unleached even where the loess is entirely leached. The contact of the loess and the till is commonly definite.

In Clay, O'Brien, southwestern Dickinson, and southeastern Osceola counties the loess is only two to three feet thick and the surface is very level. When it is less than 2½ feet thick this mantle is commonly not definite loess but a loesslike clay which may contain sand grains and pebbles throughout. When traced from the southwest it is very evident that this is the continuation of the loess mantle.

The very definite and characteristic loess of the southwestern counties of our area has been recognized as loess from the earliest geologic work done in the region. This includes the area of thick loess and that with a mantle of five to fifteen feet. The material which overlies the Iowan region and the eastern edge of the Kansan region north of Cherokee county, and which is commonly leached for its entire thickness, has not previously been definitely recognized as loess. It was called loesslike clay or loam by the writer through much of the progress of the field work, and its identity with the loess to the southwest was not demonstrated until the summer of 1916, when a series of east-west tracings were made across the entire loess-covered region with a very careful study of the changes in the loess along these lines.

In the region of thicker loess the yellow calcareous, concretion-bearing, fossiliferous loess is seen at many places. In the region of thinner loess there are few exposures and these show the noncalcareous, brownish yellow pebbleless loesslike clay. But within the region of positive loess there are some exposures in which the upper part of the loess is leached and certain level areas where the leached loess is general, and in these places the leached loess is identical with the loesslike clay (leached loess) farther northeast. Scores of exposures were studied by the writer as he passed back and forth from the region of thick loess to that of thin loess and in this way the identity of the loess of the entire region was established. The loesslike clay of the thinly veneered areas is identical in origin with the distinctive loess of more deeply covered areas.

Pebbles Within and on the Surface of the Loess

In the region of thin loess and to a large extent elsewhere a few pebbles may be found within the loess, especially in its basal part. Their distribution is of two types: (1) Pebble bands bedded in the loess, and (2) occasional pebbles scattered through the loess. Those of the first class are restricted to the basal 12 to 18 inches of the deposit and are found where the loess overlies gravel in the valleys, or on the lower slopes of the hills where the loess accumulated on a topography of some relief. In the case of the occasional pebbles scattered through the loess they are found in large part where the entire thickness of the loess is not more than three feet. It was found that many of these pebbles could be shown to occupy old burrows of animals, and in many cases where the burrow was not at first apparent a careful examination revealed it. Not every pebble found in the loess was proved to be in a burrow, but a large percentage of them was found to be so located and probably practically all have had such an origin. The burrows go from three to five feet beneath the surface and at some places are quite numerous. In some cases where the burrows passed through the loess into gravel below, the burrows appeared like tubes of pebbles in the loess. Where the loess is more than four feet thick few of the burrows go through the loess and there is no opportunity for obtaining the pebbles.

In almost any part of the loess-covered area it is possible to find a few pebbles on the surface or in the loess soil. They may be found along the public roads and less frequently in the fields. Careful search along the road enabled the writer to find one or more pebbles along practically every quarter of a mile of road where the search was made within the loess area. There are several ways by which these pebbles may have come to their present location. Where the loess is thin they may be brought up by burrowing animals from the drift beneath the loess. Many of the pebbles along the roads have dropped from the loads of gravel being hauled along these roads. The pebbles in the fields may come with manure hauled from barn lots, most of which have gravel in them. Others may have been carried from neighboring valleys in the mud attached to wheels, or to the feet of animals of historic or prehistoric times. It may be noted that during a search for pebbles, especially along the roads, one also finds nails, pieces of coal, cinders, iron, glass and crockery, bottle caps, bases of shot gun shells, etc. All these things have come to their present location by accident and were not derived from the loess beneath and likewise the few pebbles are believed to have come by accident to their position on the surface of the loess and not from within the loess.

Over much of the loess-covered region the loess does not completely cover the surface but exists where conditions were more favorable for accumulation or where erosion has been slight. The mantle of loess completely conceals the till where the surface is level or only slightly rolling, but on steep slopes the till is commonly exposed because erosion has removed the loess. The east and north slopes of hills have a thicker loess mantle than the opposite slopes or the crests of the hills, which is explained by the prevailing west and southwest winds and by the greater accumulation of the loess in the lee of the hills. Till is exposed at the crests or on the upper slopes of many hills which farther down the slopes have a complete loess covering. Under these conditions pebbles from the drift near the crest of the hill are washed down the slope onto the loess. Many examples of this condition were observed, where in ascending a loess-covered slope occasional pebbles were found and at the top of the slope the drift is exposed. It is not possible in all cases to show that the loess rests on the till, but it is possible to do this at many places. An example of this was found west of LeMars in Plymouth county west of West Floyd river on the south line of section 12, Washington township. Cuts in the lower slope show six to eight feet of loess without exposing the till but occasional pebbles are found on the road and in the gutters. Toward the crest of the hill just west of the southwest corner of section 12 the loess thins out and the till rises to the surface.

Another excellent exposure showing the relation of the till and the loess was seen in a road cut about 50 yards north of the southwest corner of the section 12 noted above. The cut extends north-south and is at the crest of a slope leading down to a valley to the north. At the crest of the hill the Kansan till rises five feet above the base of the cut and is overlain by six feet of brownish pebbly leached material (figure 17). In either direction from the crest the upper contact of the Kansan dips steeply and passes below the road grade, and the brownish leached zone thins to one foot and becomes an old soil. There is no true loess in the section at the crest of the hill, but below the crest in either direction it is present above the leached material and it

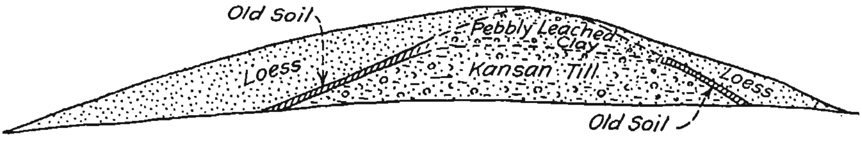

FIG. 17.—Sketch of a road cut exposure 50 yards north of the southwest corner of section 12, Washington township, Plymouth county. The sketch shows the relation of the loess to the pebbly leached clay at the top of a preloess hill, and to an old soil on the slopes of this hill.

thickens notably down the slopes, especially on the north slope, where it attains a thickness of at least 10 feet. Pebbles may be found lying on the loess on the lower slopes of the hill and no doubt they were washed down from the leached pebbly material exposed at the crest of the hill. If this were a shallow cut it would be like scores of others which were seen but in which the source of the pebbles was not so evident.

The most indefinite part of the loess mantle is commonly found near the crests of the hills where the mantle is thin. It cannot in all cases be so definitely related to the till as in the exposure just described, for if the cut is shallow, the relation of the till to the loess is not evident, and the till may appear to be above the loess which covers the slope lower down. In all cases, however, where an adequate cut exists it is evident that the sandy, pebbly material passes below the loess. This material at the crests may be distinctly different from the loess, as in the cut described above, or it may differ from the loess only in the presence of a few pebbles. In the former case it has been derived from the till, while in the latter case the bringing in of a few pebbles by burrowing animals or other means would suffice to explain the difference.

Data Concerning the Nature and Thickness of the Loess

A great number of exposures showing the loess were studied and a few of the better sections, most of which are artificial exposures, will be recorded. They are described in order from east to west along certain lines extending from the Wisconsin boundary westward across the Iowan and Kansan regions. This arrangement is followed in order to bring out the changes in thickness and nature of the loess along these lines.

From Wall Lake West across Southern Sac and Ida Counties.—At the town of Wall Lake in southern Sac county, a basement excavation just north of the water tank showed the following:

		Feet
2.	Loess, leached; including the soil	5
1.	Loess, unleached, with a few concretions and some fine sand in thin seams at the base	3

Wall Lake is less than two miles from the Wisconsin boundary, yet this material is unquestionably loess.

At the town of Odebolt, in southwestern Sac county, a basement excavation in the southwest part of town exposed the following:

		Feet
3.	Loess, leached, and soil	5
2.	Loess, unleached	1½
1.	Till, yellow	1

Another excavation one square farther south showed:

		Feet
2.	Loess, leached, and soil	4
1.	Till, yellow	2

A trench on the main street in the east part of town exposed:

		Feet
2.	Loess, leached	3
1.	Sand, yellow, with pebbles	6

The trench exposure was open for 150 feet and showed no changes laterally.

These exposures at Odebolt are just within the boundary of the Iowan drift region and the till beneath the loess may be Iowan till but it is not possible to differentiate it from the Kansan till.

Five and a half miles south of Odebolt, near the quarter-corner on the west of section 26, Wheeler township, a gravel pit in Porter creek valley showed the following:

		Feet
3.	Loess, leached	5
2.	Sand with seams of loesslike clay	3½
1.	Gravel, fresh, clean	14

In another part of the exposure the loess is seven feet thick and is leached to a depth of only two feet. This is typical calcareous loess, containing concretions and a few small snail shells. This exposure is five miles beyond the Iowan boundary, out in the rugged Kansan region, but the loess material is the same as that at Odebolt and Wall Lake. The valley in which these gravels are located continues southward to Boyer river at Boyer, in Crawford county, and in its lower course gravel material overlain by fossil-bearing, calcareous loess is exposed in several railway and other cuts.

At Arthur, in eastern Ida county, a basement excavation in the north part of town showed 4½ feet of leached loess to the base of the opening. Arthur is three miles beyond the Iowan boundary in the region of unquestioned Kansan drift and loess, yet this leached loess is identical with that found farther east at Odebolt and Wall Lake. The loess thickens to the west across southern Ida and Woodbury counties and is exposed in many road cuts. In many of the exposures on the slopes where erosion is active the unleached concretion-bearing loess comes to the surface.

From Early West across Northern Sac and Ida Counties.—At Early in west-central Sac county an excavation at the schoolhouse in the northwest part of town showed the following:

	Feet
2. Loess, leached	3
1. Till, unleached, yellow	4

Early is less than two miles from the Wisconsin boundary, and exposures along the road leading north from Early show that the leached loess, about three feet thick, continues to the edge of the Wisconsin drift.

About five miles northwest of Early a railway cut at the southwest corner of section 28, Eden township, showed the following:

	Feet
3. Loess, leached	3½
2. Loess, unleached	½
1. Till, yellow-brown, with concretions; apparently Kansan	6

At Schaller in northwestern Sac county the following section was measured:

	Feet
4. Loess, leached; including the soil	3½
3. Loess, unleached	½
2. Sand	½
1. Till, unleached, yellow-brown	2

At Galva in northeastern Ida county a trench in the road in the south part of town showed the following:

	Feet
4. Loess, leached	6
3. Loess, unleached	1
2. Sand with cobbles	2
1. Till, unleached, yellow	1

Another exposure in the east part of town showed leached loess to the bottom of a trench four feet deep.

These exposures at Early, Schaller and Galva are within the Iowan drift region and show the loess with thicknesses ranging from three to seven feet resting upon till which should be Iowan, but which could not be positively differentiated from Kansan in any of the exposures.

West of the Maple valley at Galva is the unquestioned loess region and the unleached loess is exposed in many road cuts. Near the northwest corner of section 27, Galva township, on the west slope of the Maple river valley, a highway cut exposed, in 1927, the following section.

		Feet
6. Loess, buff, leached	Peorian	3
5. Loess, buff, unleached		10
4. Loess, gray, unleached		3
3. Loesslike material, brown, leached. *Loveland*		2
2. Till, leached. *Kansan*		3
1. Till, unleached. *Kansan*		4

This is a very interesting exposure in that it shows a leached zone at the top of the Kansan, and the overlying leached, loesslike material, interpreted as Loveland, below the unleached base of the Peorian loess. Exposures of this type are more usual in the typical Kansan region of western Iowa farther south, but this is the most northern known exposure of this type in northwestern Iowa.

At Holstein in north-central Ida county a trench exposure on the street showed the following:

	Feet
4. Loess, leached, including black soil	4½
3. Loess, unleached, yellow-brown, mottled, with a few concretions	4½
2. Seam of sand	¼
1. Till, unleached, yellow	2

The divide cut on the railway one mile east of Holstein exposed the following:

	Feet
3. Loess, leached	4
2. Loess, unleached	2
1. Till, yellow, with concretions	3

This series of exposures from Early through Schaller and Galva to Holstein extends from the Wisconsin boundary across the Iowan area into the unquestioned loess-covered Kansan. The loess is thicker to the west, and with this increased thickness the unleached zone appears, but the leached loess is the same at all places. Within a short distance west of Holstein the country is rugged and loess exposures are common in the road cuts. The loess thickens to the west across Woodbury county to Sioux City, where loess exposures 30 to 50 feet deep may be seen.

From Storm Lake across Buena Vista, Cherokee and Plymouth Counties.—At Storm Lake a basement excavation on the main street showed the following:

	Feet
4. Soil	2
3. Loess, leached	2
2. Loess, unleached	1
1. Till, yellow, unleached	2

This exposure is within one mile of the Wisconsin boundary and in other exposures in the east part of town the loess may be found to, and possibly beneath, the Wisconsin drift.

At Alta excavations along the railway just west of the station and in the divide cut in the west part of town showed three feet of leached loess with soil overlying unleached grayish yellow till with some concretions. This is at the crest of the great divide. The till exposed here and at Storm Lake is the light yellow till phase that is interpreted as Iowan.

In southwestern Buena Vista county, in the southwest quarter of section 21, Maple River township, a well boring passed through five feet of loess, and at the time of the writer's visit the well had been sunk to a depth of 50 feet, all in yellow till. This is an exceptional thickness for the oxidized zone of the till. This locality is within the Iowan drift region, but most of this thickness probably is Kansan till.

Just east of the Little Sioux east of Cherokee along the south line of sections 25 and 30 there are a number of cuts which exposed four to six feet of loess, and in at least two cases about a foot of unleached loess containing concretions was shown beneath the leached material. The first cut east of the southwest corner of section 30, Afton township, showed at the center till overlain by two to three feet of dark loesslike clay which contains some pebbles. In either direction down the slope this material becomes thicker and grades into typical loess without pebbles. An exposure on the south side of the road east of a ravine on the north line of the northeast quarter of section 36, Cherokee township, showed a mantle of about three feet of leached loess resting directly on the unleached till. At the contact are several gravel masses partly inclosed in the till and overlain by the loess. These are included gravel masses in the till which were exposed at the surface at the time the mantle of loess was deposited.

At Cherokee, at the new hospital in the north part of town, about 50 yards northwest of the building, a trench showed the following:

		Feet
4.	Soil	2
3.	Loess, leached	2½
2.	Loess, unleached, with a few concretions and containing thin layers of fine sand at base	1
1.	Sand with pebbles	2

This exposure is on the high gravel bench of the Little Sioux valley, about 125 feet above the river. The position of the loess over the sand and gravel of the bench area shows that the gravel deposit of the high benches is older than the loess. A cut on Spruce street in the north part of town just east of Second street shows three feet of loesslike material overlying the gravel. The upper two feet of the zone is leached.

In 1916 a road in the northeast part of section 28, Cherokee township, had been recently graded and showed a number of good sections. The first cut north of the Cherokee water tank showed the following:

		Feet
4.	Loess, leached; including the soil	4
3.	Loess, unleached	2
2.	Sand and pebble layer	¼
1.	Till, yellow-brown, with concretions. *Kansan*	2

The third cut north of the water tank, at a bend of the road, showed the following:

		Feet
5.	Loess, leached; including the soil	4½
4.	Loess, unleached	1½
3.	Loess, sandy	1½
2.	Pebble and sand layer	½
1.	Till, yellow, with included gravel masses. *Kansan*	2

In the loess zone of this exposure a section of a small elephant tusk about six inches long was found. Other cuts northwest to the viaduct across the spur of the railway show similar exposures. The first road cut east of this viaduct showed:

		Feet
3.	Loess, leached	6
2.	Loess, unleached	2
1.	Sandy material, fine-grained, clayey	2

A railway spur in the southeast quarter of section 21 and the north part of section 28, on the grounds of the Cherokee State Asylum, showed in 1916 some newly made cuts. At the edge of the creek valley in the southeast quarter of section 21 the cuts showed 30 feet of typical brownish yellow Kansan till with large included sand and gravel masses. A thin zone of leached loess was exposed at the top of the cut.

The largest cut along this spur is at and just south of the north line of section 28. The Kansan till rises 15 to 20 feet in the cut and has included in it as lenses much material that is not typical Kansan. Just south of the section line there are several masses of Nebraskan till included in the Kansan. One of these, an elongate lens, is more than 50 yards long and six to eight feet thick and is somewhat mixed with yellow Kansan till. Another smaller mass consists of leached Nebraskan till. The upper contact of the till in this cut shows some small relief features not expressed in the present topography; that is, certain small irregularities in the till surface were filled in and obliterated by the sand and loess.

At one place in this cut a section exposed by cleaning a strip down the face of the cut was as follows:

		Feet
9.	Loess, leached; including the soil	6
8.	Loess, unleached	2
7.	Loess and fine sand in alternating layers	4
6.	Pebble layer	¼
5.	Till, unleached, yellow, with concretions	3
4.	Till, unleached, blue-gray, pebbly, with a few concretions	2

3.	Clay, noncalcarous, dark brown, pebbleless	3½
2.	Till, blue-gray, similar to No. 4	2½
1.	Till, yellow. *Kansan*	2½

All the material below the pebble layer (No. 6) probably is Kansan drift, numbers 4, 3 and 2, which are not typical Kansan, being interpreted as included material. It appears that the noncalcareous brown clay (No. 3) is material gathered up from some surface by the Kansan ice sheet. The marginal parts of this included mass became mixed with the Kansan till, forming horizons 4 and 2 above and below it. The exposure was so badly slumped that it was not possible to determine the lateral extent of zone 3, but it is not present generally throughout the cut.

An alternative interpretation for the foregoing exposure is to extend the Iowan west of Mill creek and Little Sioux river and make zones 5 and 4 Iowan till. Zone 3, the brown noncalcareous, pebbleless clay, would then be the leached Loveland loess resting on Kansan till. An exposure along the highway in the northeast part of section 28 also showed some dark leached clay, but its relation to the till could not be determined. However, if the Iowan is extended west of Little Sioux river at Cherokee, one cannot see why it should not extend on west across western Cherokee and Plymouth counties. It seems better to interpret the noncalcareous material as an inclusion.

Near the south end of this large cut, where the till had passed below the grade, the following section was measured.

		Feet
3.	Loess, leached; including the soil	6
2.	Loess, unleached	3
1.	Loess and fine sand in alternating layers	4

A small cut at the level of the upland just northwest of the buildings showed:

		Feet
3.	Loess, leached; with soil	4½
2.	Loess, unleached	1
1.	Till. *Kansan*	2

This illustrates the usual thinning of the loess on the hilltops as compared with the east or north slopes.

About a mile southwest of Cherokee, in the north part of the southeast quarter of section 33, on the north slope of a ravine valley, are some abandoned clay pits which show the following section.

		Feet
4.	Loess, leached; including the soil	5
3.	Loess, unleached, containing a few concretions	15
2.	Loess, sandy, silty, with a few layers of fine sand	5
1.	Slumped to bottom of pit	10

The material in the lower part of the exposure (No. 2) has a faint horizontal banding and may be partly waterlaid. It grades upward into the more typical loess, which here has an exceptional thickness for this region. The unleached loess (No. 3) is filled with the brown threadlike rootlet impressions which are characteristic of the loess. The top zone of leached loess is the same as that which is found in most road cuts. It is believed that number 2 and possibly part or all of number 3 represent the Loveland, here directly overlain by the Peorian loess. This deposit was formerly used for the manufacture of brick and tile.

Western Cherokee and eastern Plymouth counties have a loess mantle of sufficient thickness to conceal the till on all but the steeper slopes. The shallow road cuts show dark soil passing into the leached loesslike clay below. Some cuts of four feet or more in the loess show the unleached phase. An exposure just south of the northwest corner of section 29, Sheridan township, Cherokee county, showed the usual horizons.

		Feet
4.	Loess, leached	3½
3.	Loess, unleached	2
2.	Sand, fine, yellow	1½
1.	Till, yellow. *Kansan*	1

On the west side of the West Fork of Little Sioux river in the south part of section 23, Amherst township, a gravel pit showed the following section, which includes the horizons commonly existing along the valleys.

		Feet
5.	Loess, leached	3
4.	Loess, unleached, with pebbles in basal 6 inches	1
3.	Sand with pebbles and becoming more clayey above	4
2.	Gravel, medium-grained, with a few cobbles	5
1.	Till, fresh, yellow. *Kansan*	2

Similar conditions continue for several miles west of LeMars, but within the more rugged country the loess is thicker and the unleached concretion-bearing phase is at the surface.

About 40 rods south of the northwest corner of section 32 of Henry township, Plymouth county, the following section was exposed.

		Feet
2.	Loess, buff, calcareous. *Peorian* Contains many calcareous concretions and has some fine-grained sand in basal part.	8
1.	Loess, brownish gray, leached. *Loveland* Contains some calcareous concretions, apparently of material carried in from above.	3½

Another cut near by showed Kansan till beneath the brownish gray loess.

O'Brien and Sioux Counties.—At Sutherland, in southeastern O'Brien county, at the southwest corner of town, a post auger hole was bored through soil and leached loess to a depth of three feet and eight inches without reaching the base of the loess. In the east part of town are several pits in the gravel deposit along the headwaters of Murry creek that show 3½ feet of leached loess overlying the gravel.

Road cuts in northern Cherokee and O'Brien counties commonly show the black soil, which at a depth of 12 to 18 inches grades into the yellow leached loess. If the exposure is over three feet deep the unleached yellow till is commonly shown. A good series of road cuts was exposed along the township line road leading south from Primghar. One of these road cuts in the southwest quarter of section 7, Highland township, showed 3½ feet of leached loess overlying unleached till of the Iowan type. A road cut passing beneath the railway on the east line of section 12, Union township, showed five feet of leached loess over 12 feet of light yellow calcareous till which apparently is Iowan. An exposure near the southwest corner of section 8, Liberty township, showed from above downward: (1) Leached loess, 3½ feet; (2) unleached gray gravel, 8 feet; (3) yellow Iowan till.

About half a mile north of the Sheldon railway station in a cut on the Chicago, St. Paul, Minneapolis and Omaha railway, the following section was measured.

		Feet
4.	Soil	2
3.	Loess, leached	1½
2.	Loess, unleached	2½
1.	Till with calcareous concretions	1

Farther north near the crossing of Floyd river, abandoned gravel pits show a zone of leached loess three to five feet thick overlying the gravel. All these exposures of O'Brien county are in the Iowan region.

In Sioux county, Sheridan township, at the southwest corner of section 29, an excavation for a storm cave in the schoolhouse yard showed eight feet of loess, the larger part of which is leached. Below the loess is a thin layer of sand and pebbles and then the unleached Kansan till. Two miles north, at the southeast corner of section 18, in the schoolhouse yard, material thrown from an excavation for a storm cave showed that the loess has a similar depth, for the till was not reached. At the northeast corner of section 32, Lincoln township, an excavation for a cistern showed 10 feet of loess without reaching its base. Careful search on the walls of the cistern and of the material thrown out did not show a single pebble.

Farther west in Sioux county, loess exposures are numerous but commonly show only the leached loess, except in the more rugged region near Big Sioux river, where unleached concretion-bearing loess is found.

Clay and Dickinson Counties.—In Clay county, Douglas township, near the quarter-corner on the south of section 25, an open trench showed the following:

		Feet
4.	Soil	1
3.	Loess, leached	1
2.	Loess, unleached, with a few concretions	½
1.	Till, yellow, with a few concretions	2

This exposure is just half a mile west of the north-south center line of Clay county and within four miles of the Wisconsin boundary across the Little Sioux valley, but the loess horizon, although thin, is sufficiently well developed to be definitely recognized. To the north in central Clay county, towards Spencer, the loess horizon is thinner and in some places, where it is less than two feet thick, it is not a definite loess zone. It forms, however, a thin mantle of dark to yellow clay commonly concealing the till and when it is traced from the counties to the west it is seen to be very definitely the equivalent of the loess. This is the condition over northern Clay and southwestern Dickinson counties outside the Wisconsin boundary.

Osceola and Lyon Counties.—In southeastern Osceola county, Harrison township, on the south line of the southwest quarter of section 2, a post auger hole gave the following section.

		Feet
3.	Soil	1½
2.	Loess, leached	2
1.	Till, yellow	

On the west line of section 3, Harrison township, an open trench showed the following:

		Feet
3.	Soil	1
2.	Loess, unleached, with concretions and iron tubules	1½
1.	Till, yellow	3

On the north line of the northwest quarter of section 28, Ocheyedan township, a post auger hole gave the following section.

		Feet
3.	Soil	1½
2.	Loess, unleached, with concretions	1½
1.	Pebble zone	

All three of these sections are within one mile of the Wisconsin drift boundary and yet they show the loess horizon.

Road cut exposures in southern Osceola county commonly show the leached loess, which has a thickness of 2½ feet and rests directly on the unleached till.

At Sibley, a trench just east of the intersection of the main streets showed the following section:

		Feet
4.	Fill, chiefly of black soil	2
3.	Soil, dark, peaty, passing into leached loess	2½
2.	Loess, unleached, with concretions and dark rootlike threads through it	1
1.	Till, brownish yellow	1

This trench was open from the intersection of the main streets south for two blocks to the Rock Island railway and the loess was essentially the same all the way. At the first street crossing (near Windsor Hotel) gravel appeared below the loess and thickened to the south until the till dropped below the bottom of the trench. The gravel was said to be five feet thick near the railway. An open trench east of the park in the northeast part of town showed similar relations of the loess, till and gravel (figure 18, page 143), and the gravel of the pits in the east part of Sibley is overlain by three to four feet of leached loess.

At Little Rock, in northeastern Lyon county, a cellar excavation in the west part of town showed the following:

		Feet
4.	Soil, passing to yellow clay at base	1½
3.	Loess, leached	1
2.	Pebble band	¼
1.	Till, unleached, yellow, with small calcareous concretions near the top	6

Other exposures in the region show 2½ to 3 feet of leached loess, as near the southeast corner of section 35, at the northeast corner of section 22, and near the southeast corner of section 18, all in Elgin township. All of these exposures noted in Osceola and Lyon counties are in the Iowan drift region. Farther west, in Lyon county, on the Kansan region, the leached loess may be seen in many exposures, and in the more rolling country near the Big Sioux the unleached loess with concretions is commonly exposed.

Southern Nobles County, Minnesota.—The study of the loesslike clay was continued about 10 miles north of the state line to Adrian in Nobles county, Minnesota. At the southwest corner of section 28, Ransom township, less than two miles from the Wisconsin drift boundary, a post auger hole exposed 2½ feet of soil and loesslike clay overlying yellow till with calcareous concretions.

At the quarter-corner on the east line of section 19, Little Rock township, a post hole showed the following section.

		Feet
4.	Soil, passing to leached loess below	1½
3.	Clay, loesslike, slightly sandy and with a few concretions in lower 6 inches	1
2.	Sandy pebbly zone	½
1.	Till, yellow-brown, unleached, with small calcareous concretions	

At the quarter-corner on the east of section 12, Grand Prairie township, a post hole showed the following:

		Feet
3.	Soil and leached loess	2½
2.	Pebbly band	½
1.	Till, yellow	

Three miles south of Adrian at the southeast corner of West Side township, a post hole showed the following:

		Feet
3.	Soil, becoming yellow at base	2
2.	Loess, unleached, slightly sandy	2
1.	Till, yellow-brown	½

The last three records are located along the crest of the ridge running south from Adrian which Wilder interpreted as the Altamont moraine[42] and are within the area mapped by Leverett and Sardeson as Wisconsin outside the prominent moraine.[43]

The loess mantle in the Adrian region is thin, as the area is far to the northeast of the region of thick loess and so is similar to Clay and southern Dickinson counties farther south. The exposures east of Adrian are not of the typical leached loess, but sand grains exist more or less throughout the whole of it. It is, however, the equivalent of the loess mantle.

ORIGIN AND AGE OF THE LOESS

That loess is of eolian origin has become firmly established.[44] The chief source of the loess material of our region was the valley flats of the great rivers forming the west line of the state; especially Missouri river, and because the prevailing winds of the region are from the west, the thickness deposited and the extent of the mantle are greater to the east than to the west of the valleys. The greatest thickness was deposited near the Missouri and Big Sioux river valleys in western Woodbury and Plymouth counties, where thicknesses of 30 to 50 feet exist, producing the distinctive loess-formed topography of that region. With increasing distance to the east and northeast the thickness of loess deposited decreased. It was 10 to 20 feet over Woodbury, Ida, southwestern Sac and western Plymouth counties; it was five to ten feet over western Cherokee, eastern Plymouth, Sioux and Lyon counties; it was three to six feet in northwestern Sac, eastern Cherokee, western Buena Vista, O'Brien and western Osceola counties; and it decreased to one to three feet in Clay and southwestern Dickinson counties. It covered all the Kansan drift region and all the Iowan drift region now exposed eastward to the Wisconsin boundary, although in Clay county it was very thin.

At the south end of the Iowan area in southwestern Sac county the

42 Iowa Geol. Survey, Vol. X, pp. 132-135, 1900.

43 Minnesota Geol. Survey, Bull. 14, p. 51 and map in pocket.

44 A bibliography on loess is given in Iowa Geol. Survey, Vol. XXII, pp. 582-592. Professor Shimek discusses the matter briefly, from the standpoint of the evidence of western Iowa, in Vol. XX, pp. 399-405, and lists in a footnote on page 399 some of his more important papers on the subject.

thickness of the loess decreases abruptly at the Iowan boundary from 10 to 20 feet on the Kansan region to the south to three to five feet on the Iowan. This suggests that the Iowan region was protected in some way, possibly by the presence of the ice, or that conditions were more favorable for accumulation on the Kansan region. This abrupt thinning of the loess at the boundary is similar to the condition which exists around the southern border of the Iowan area of northeastern Iowa. Farther northward, where the thick loess does not approach the Iowan boundary, the thinner loess mantle passes across this boundary without any perceptible change.

Little evidence exists in northwestern Iowa as to the exact age of the loess. This is due to the questions as to the exact age of the drift sheets of the region. Just south of our region in Crawford and Carroll counties the Missouri river loess mantles a mature erosional topography which was developed from the Kansan gumbotil plain. It is, therefore, later than the erosion of the Kansan gumbotil plain. This loess mantle of Crawford and Carroll counties is without doubt the one that continues over all of northwestern Iowa to the Wisconsin drift boundary. The loess terminates on the east at the Wisconsin boundary, and in Carroll county to the south there are exposures showing the Wisconsin drift on top of the loess.[45] The loess is, therefore, pre-Wisconsin.

It is generally agreed that the great loess deposit of the Missouri river region is of the same age as the great loess deposit of eastern Iowa, which is placed in the Peorian interglacial age and seems to have followed closely the Iowan ice age. If this correlation of the great loess deposits of western and eastern Iowa is correct, then it follows that the loess of northwestern Iowa east to the Wisconsin boundary is Peorian in age.

The significance of the determination recorded above, that the equivalent of the Missouri river loess continues unbroken to the Wisconsin boundary, is that it makes the "intermediate" region pre-Missouri-river loess in age and, by the correlation noted above, pre-Peorian in age. Since the loess of this region rests directly upon a fresh, unleached till, it would seem to follow that this till is Iowan; that is, that the "intermediate" region is an Iowan drift region in northwestern Iowa, similar to the Iowan region in northeastern Iowa. However, this correla-

[45] Iowa Geol. Survey, Vol. IX, pp. 89-92, 1899.

tion of the till of the "intermediate" region with the Iowan, on the basis of the freshness of the till beneath the loess, is not very strong, since the till of all of northwestern Iowa over the Kansan region as well is fresh, unleached till, and it has not been possible in most cases to differentiate a till distinct from the Kansan in the "intermediate" region.

CHAPTER V

THE VALLEY GRAVELS

Gravel deposits exist along many of the stream courses of northwestern Iowa. They are found along the larger rivers, along the medium-sized streams, along the small creeks even nearly to their heads on the uplands, and they fill in certain broad areas on the headwaters of some of the streams. As a rule the present stream channels are cut into the gravel fillings, while the parts which remain form terraces which differ greatly in height, some of them being as much as 100 feet above the streams.

The valley gravels are present in both the Iowan and the Kansan drift regions. In both regions they lie upon unleached yellow till and are overlain by loesslike clay which has been shown to be the continuation of the Missouri river loess. There are also gravels within the valleys of the Wisconsin drift region, but these gravels are not discussed here. Several of the larger rivers of northwestern Iowa head northeastward within or along the Wisconsin drift margin and therefore must have carried drainage from the Wisconsin ice. This is true of Big Sioux, Rock, Little Sioux and Boyer rivers. The drainage basins of Floyd and Maple rivers, however, are entirely beyond the margin of the Wisconsin ice. Also many of the tributaries of those stream valleys which carried Wisconsin drainage are entirely beyond the margin of the Wisconsin ice.

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 probably 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.

NATURE OF THE GRAVELS

The material is mostly coarse sand and fine gravel, and the extremes in either direction, coarse gravel or silty sand, are rare. The material is horizontally bedded, but not well assorted and the layers in most cases are 10 to 12 inches thick rather than thin beds. Some of the layers are cross-bedded, with lens and basin structures. Another common condition, especially along small valleys, is thick layers of sand with small pebbles up to one or two inches in diameter scattered through it.

The material is distinctly fresh and commonly is without the least indication of iron-rusting or other alteration. Much of the sand, 70 to 80 per cent of the whole, is quartz. Among the pebbles there are many kinds of rocks, but gray limestone pebbles are most abundant and give to the whole deposit a light color. The average of eighty-eight analyses of pebbles from the valley gravels is: Igneous rocks 37 per cent, of which 23 per cent are granite; and sedimentary rocks 63 per cent, of which 56 per cent are limestone (pages 176 to 180). The percentage of the igneous and other resistant kinds of pebbles is larger down the valleys and to the west and southwest. In comparison with the material of the gravel hills, these valley gravels contain 13 per cent more of igneous rocks. This is perhaps the result of the destruction of the clay-balls and shale pebbles and a consequent relative increase of other kinds. The number of limestone pebbles worn out largely offsets the relative increase due to the destruction of the clay-balls, so that most of the increase is in the igneous rock pebbles.

DISTRIBUTION AND DESCRIPTION OF THE VALLEY GRAVELS

The Big Sioux River Drainage Basin

The Main Valley

Big Sioux river drained the east margin of the Dakota lobe of the Wisconsin ice sheet from the head of the Coteau des Prairies southward to Canton, and received through its larger tributaries drainage from the west margin of the Des Moines lobe. It also received the drainage from the Iowan ice edge in southwestern Minnesota and in

Lyon county, Iowa. The valley contains a gravel deposit south of the northwest corner of Iowa and at several places this deposit forms prominent terraces. These gravels and these terraces were not studied in sufficient detail to separate the Iowan and Wisconsin, if in fact this can be done.

Near the northwest corner of the state, west and northwest of Granite (Plate I), there is a terrace area two miles long and one-half to three-fourths of a mile wide (Granite terrace). The surface altitude is 1330 to 1345 feet above sea level, or 80 to 90 feet above the river. At the south end of the bridge on the west line of section 19 just west of Granite, the terrace gravel is 20 feet thick and rests on Kansan till, which continues down to the creek level, 20 to 25 feet lower. The north slope of the valley at this place shows 20 to 25 feet of fresh gravel and sand below the terrace. About a mile west of Granite, in the southwest quarter of section 24, the Chicago, Rock Island & Pacific Railway Company formerly operated a gravel pit in the terrace. The following section was exposed in the pit and in a gully below.

		Feet
4.	Soil, etc.	3
3.	Bowlder bed, badly iron-rusted and partly cemented The coarse-grained igneous bowlders are rotted, and the limestones are decayed to brown masses.	4
2.	Gravel and sand, relatively fresh	16
1.	Till, brownish yellow. *Kansan* Continuous exposure for 5 feet at top and at intervals for 30 feet.	35

The gravel horizon in the two exposures noted has a thickness of about 20 feet, but these exposures are located along the continuation of Blood Run valley across the terrace, and the average thickness of the deposit over the whole area is probably less.

South of Blood Run the terrace continues as a narrower belt across sections 26 and 35 and is terminated by an eastward bend of the river just south of the township line. It begins again in section 7, Centennial township, and with a width of about a mile continues south to Klondike (Klondike terrace). The Klondike terrace is only 45 to 55 feet above the river or 30 to 40 feet lower than the Granite terrace. The material was seen just east of the bridge at Klondike, where it is a coarse gravelly deposit, and in the north part of section 17, where it is largely coarse gravel with bowlders and is partly cemented. In the latter exposure the gravel rests on a tough dark drift which Shimek interpreted as "probable Nebraskan".[46]

From Klondike south to Canton the river follows the Iowa bluff, and

[46] Shimek, B., Pleistocene of Sioux Falls and Vicinity: Bull. Geol. Soc. Amer., Vol. 23, p. 144, 1912.

the Dakota side, although rising gradually, does not present a distinct terrace. Along this portion of the Big Sioux valley the Dakota lobe of ice pushed up to the river and such gravel deposits as exist are probably of Wisconsin age.

South of Canton, terraces appear at various places along the valley to Hawarden and Chatsworth. The river swings from side to side of the valley and the terraces are found here on one side and there on the other. The altitude of these benches is 20 to 30 feet above the river, decreasing southward.

Rock River Valley

Rock river heads in northeastern Pipestone county, Minnesota, on the slope of the Coteau des Prairies. It drains most of the Iowan belt in Minnesota and has the heads of its several branches in the edge of the Wisconsin region. Rock river enters Iowa at the center of the north line of Lyon county and flows southward and southwestward across Lyon and northwestern Sioux counties to Big Sioux river. Aided by its tributaries from the east it drained about 50 miles of the Wisconsin ice margin and an equal length of the Iowan belt. It was, therefore, well located to receive gravel deposits from both of these ice sheets.

South of the state line the valley flat is about a mile wide, and much of this flat is a terrace about 25 feet above the river. Rock Rapids, Doon and Rock Valley are located on this terrace. At the mouth of Rock river valley the terrace unites with that of the Big Sioux, making a large level plain several miles across.

At Rock Rapids the gravel is 25 to 30 feet thick and rests on yellow Kansan till. A pit about half a mile north of Rock Rapids showed cross-bedding and basin structure and variations in the coarseness of the material. At Doon the gravel deposits have been extensively worked in the past by the Great Northern Railway Company. A pit face here showed 25 feet of gravel, which was said to continue without change for at least five feet below the pit bottom. At Rock Valley the town well is 18 feet deep and is entirely in gravel, and the Chicago, Milwaukee, St. Paul & Pacific Railway pit west of town has a depth of 20 feet, without reaching the base of the gravel. The material exposed at all these places along Rock River is relatively fresh, oxidized but unleached, and consists of sand and fine-grained gravel with few cobbles or bowlders. Cross-bedding, inclined-bedding and basin structure are common.

Tributaries of Rock River

Little Rock River and Otter Creek.—Little Rock river, the principal tributary of Rock river from the east, heads in southern Nobles county, Minnesota, within and along the Wisconsin drift margin. In Iowa it crosses the northwest corner of Osceola county and flows south and west across eastern Lyon county to its union with Rock river. Its course southward to where Otter creek enters is within or along the margin of the Iowan area. This stream, therefore, like Rock river carried both Iowan and Wisconsin drainage. There are gravel deposits along the valley at various places, forming indistinct benches which merge more or less gradually with the flood-plain level which forms the major part of the area between the valley slopes. On the Lyon county map Wilder showed this area as a Wisconsin gravel train with a width of about half a mile and extending continuously along the stream.

Just opposite Little Rock there is a low terrace with gravel exposures, and in the northeast part of the town is a small gravel pit in the terrace. The material is horizontally bedded and consists of fresh gravel and sand which is poorly assorted. The gravel of the pit is overlain by two feet of sandy, loesslike material which grades into the soil above.

At George, 10 miles below Little Rock, the terrace on the north side of the valley is almost half a mile wide and 15 feet above the river. The south part of the village is on this terrace, and the town well, southeast of the railway station, has the following log.

		Feet
4.	Soil	3
3.	Loesslike clay	7
2.	Gravel and sand, very fresh	12
1.	Yellow clay	

Otter creek heads just within the Wisconsin drift margin north of Bigelow, Minnesota, flows south along this margin for several miles and at the time of maximum glacial advance drained about 10 miles of the ice-margin. It has an irregular course southward across western Osceola county, and thence flows west and north in southeastern Lyon county to its union with Little Rock river southwest of George. Its entire course is within or along the margin of the Iowan drift region.

This valley has very little gravel in its upper course near the Wisconsin drift margin, but from Gilman township in southwestern Osceola county across southeastern Lyon county gravel terraces are common. The material exposed in the terrace at Ashton is fresh, only the coarse-grained biotite granites being altered. An analysis of pebbles here showed the presence of 35 per cent igneous rocks and 65 per cent sedimentary rocks, 64 per cent of the latter being gray and buff limestones. On the county line northeast of Matlock, Otter creek valley is a broad shallow depression with a broad flood plain and a narrower gravel terrace about 15 feet above the stream.

Rat creek, a tributary of Otter creek in southeastern Lyon county, flows in a broad sag 15 to 25 feet below the upland. The valley contains some gravel, and indefinite low benches appear at several places. On the Lyon county map, Wilder mapped a Wisconsin gravel train along the entire length of this creek. The valley is in the Iowan drift region, entirely beyond the Wisconsin region, and did not receive Wisconsin outwash.

Area East and Southeast of Sibley.—At the edge of Sibley there are some large gravel pits in a deposit that is not along any present stream course. The deposit has an areal extent of at least 80 acres and underlies the east and south parts of Sibley. In the City pit 25 to 30 feet of gravel and sand were exposed, and the Chicago, Rock Island & Pacific Railway pit to the south showed 18 feet of gravel. The gravel rests on an uneven surface of unleached till, which at one place in the City pit slopes four feet in a horizontal distance of 30 feet, and greater irregularities are said to exist. Several mounds of till appear in that part of the railway pit from which the gravel has been removed. One of these consists of a mass of till with the gravel beneath it on at least one side, and in another the till has irregular contacts with the surrounding gravel, and may also be an included mass of till.

A small pit just west of the larger pits showed, in 1927, a lens of till 25 feet across on the pit face and four feet thick, at the top of the gravel horizon. It is light yellow unleached till, resting on unleached gravel and is overlain by 3½ feet of leached loess. The gravel and till are certainly of the same age and certainly Iowan.

The gravel of these pits is, in general, fresh. At the top is a zone of coarse material, several feet thick, which is iron-stained, and near its base the gravel is in places stained a dark color. A well in this gravel area in the east part of Sibley stopped on a "cement rock" layer which is probably at the base of the gravel. Most of the dark coarse-grained igneous rock pebbles are decayed so as to crumble easily, limestone pebbles are abundant and unaltered, and many layers or laminæ contain a large percentage of grains of shale. The gravel is medium-grained and quite uniform. Bowlders are rare except at the base of the gravel, where they rest on the till.

A sewer pipe trench along the street just east of the City Park in the northeast part of Sibley was open in August, 1911, and showed at the south, sand and gravel overlain by loess. To the north fresh till rose above the level of the bottom of the ditch, the sand and gravel horizon thinned to zero, and the loess rested on the till. A sketch of this exposure is shown in figure 18. The exposure was apparently at the edge of the

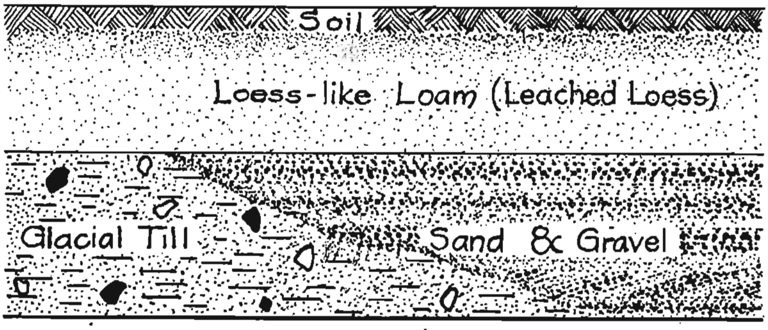

FIG. 18.—Sketch of exposure in side of sewer pipe trench in the northeast part of Sibley. It shows the relation of the gravel horizon to the till, and of the loess to both the gravel and the till.

gravel deposit and showed the relation of the gravel to the till and the relation of the loess to both the gravel and till. None of the contacts showed any alteration. Similar conditions were seen in an open trench along the north-south main street of Sibley at the street crossing near the Windsor Hotel (page 133).

Two miles southeast of Sibley, in the northeast quarter of section 30, East Holman township, a gravel pit operated by the Chicago, Rock Island & Pacific Railway Company exposed material similar to that at Sibley except that the upper part is coarser and more bowldery. Eighteen feet of gravel was exposed beneath a five-foot zone of loesslike clay. A considerable area south of this pit in sections 30 and 29 is quite level and is probably underlain with gravel.

The margin of the Wisconsin drift as traced by the writer is only a few miles to the northeast of these deposits east and southeast of Sibley, but the small valleys leading away from this Wisconsin drift margin show no indication of having carried outwash material, and the small valley of section 18, which passes near the deposit east of Sibley, did not head back to the margin of the Wisconsin ice. Also these gravels are overlain by loess which is older than the Wisconsin epoch and at one place are overlain by a great lens of Iowan till. In appearance and composition these are the typical valley gravels of the Iowan drift region.

Tom Creek.—This creek drains a part of northeastern Lyon county near the state line and enters Rock river at Rock Rapids. There are gravel terraces along its course and fresh gravel and sand may be seen in several valley pits in Midland township. A similar deposit is found along the north branch of Tom creek.

Tom creek and Little Rock river drain the area in northeastern Lyon county mapped by Wilder as Wisconsin outwash.[47] Otter creek drains the similar outwash area in northwestern Osceola county. Although these areas have some gravel outside the present valleys, it is not sufficient to form an outwash plain and they are not related to the Wisconsin boundary. Several of the more important gravel deposits along these valleys are overlain with loess and probably essentially all of the gravel is of Iowan age.

Mud Creek.—This creek heads in the southern part of Rock county, Minnesota, and flows south by southeast across Lyon county to Rock river near Doon. From the state line southward the valley is broad with gentle slopes and a flat bottom. This flat is, as a rule, a flood plain, but benches of gravel appear at many places. The gravel is fresh and consists of relatively resistant material. Three analyses of pebbles from benches along this valley show an average content of 51 per cent of igneous rocks, which is 14 per cent higher than the average for pebbles from the valley gravels. The analyses also show a high percentage of quartzites and cherts, which are classed with the sedimentary pebbles. This valley is entirely within the Kansan drift area and could not possibly have received any outwash from the Iowan area as here mapped.

Rock river, Little Rock river and Otter creek all head at the Wisconsin margin and therefore carried Wisconsin drainage. The headward courses of Rock and Little Rock rivers in Minnesota were not studied but the upper course of Otter creek valley does not contain much gravel. Further, the gravel of these valleys is overlain by the loess or loesslike clay that covers the Kansan and Iowan drift regions and which is older than the Wisconsin. These gravels are, therefore, believed to be of Iowan age. The gravels just east and southeast of Sibley, within the Iowan area and those along Tom creek in Midland township, just outside the Iowan area, apparently are of Iowan age. The gravels along Mud creek in western Lyon county could not have been derived from the Iowan and are believed to have been released from the Kansan till by erosion and to have accumulated in the valley. The greater dominance of the resistant types of pebbles might be thus accounted for.

Small Tributaries of the Big Sioux

None of the creeks considered under this heading is more than six to ten miles long and all lie entirely within the Kansan drift region. The first of these south of the state line is Blood Run, which flows southwest-

[47] Iowa Geol. Survey, Vol. X, p. 135 and map, 1900.

ward across Sioux township in northwestern Lyon county, and joins the Big Sioux valley west of Granite. The Granite terrace of the Big Sioux valley (page 139) continues into the mouth of Blood Run valley as far as Granite, and gravel deposits appear to the east along the valley through sections 20, 21 and 22.

Plum creek enters the Big Sioux valley along the south edge of the Klondike terrace a few miles south of Blood Run. This creek was not followed, but Beyer describes it as having a low indistinct terrace of small extent, and describes a pit exposure along the creek, three miles south of Larchwood, as showing seven to eight feet of clean sand and gravel resting on the blue clay.[48]

Dry creek and Six Mile creek, in western Sioux county, have broad, open valleys with narrow flood plains, and gravel deposits appear along them at various places, but nowhere do they form benches of any prominence. Similar gravel deposits are found along the creeks of western Plymouth county, especially along Broken Kettle creek, and in this region the gravel is overlain by a deposit which is unquestionably loess. The gravel of all these small tributaries of the Big Sioux must have been derived from the Kansan till.

The Floyd River Drainage Basin

The Main Valley

Next east of the Big Sioux lies the Floyd river basin. This is a smaller basin lying between the Big Sioux and the Little Sioux and is limited to the north by the spread of the basins of its larger neighbors. Floyd river heads in southern Osceola and northern O'Brien counties and flows south by southwest across eastern Sioux and central Plymouth counties to Missouri river at Sioux City. The Floyd drainage basin is separated from the Wisconsin drift area by the high divide of southern Osceola county and certainly received no drainage from the Wisconsin ice. Its headwaters northeast of Sheldon are within the Iowan drift area, of which it drains about 150 square miles. Southwest of Sheldon across Sioux and Plymouth counties the basin is within the Kansan drift region.

In northwestern O'Brien county there are small benches in the Floyd valley 10 to 20 feet above the stream. Exposures in these benches are not common, but one on the west side of the valley on the north line of section 21, Floyd township, showed three feet of horizontally bedded gravel overlain by about 18 inches of leached loess.

48 Iowa Geol. Survey, Vol. XXIV, p. 426, 1914.

About one mile north of Sheldon on the south side of the Floyd valley there is a large abandoned gravel pit and there are also some smaller pits that are now being worked. In the abandoned pit west of the railway the following section was exposed.

		Feet
3.	Black soil	1½
2.	Loesslike clay, brownish yellow, leached, containing a few pebbles. This member grades into the soil above, and in some places, by the inclusion of pebble bands, it grades into the gravel bed below. Although not true loess in the lithological sense, this material is certainly the time equivalent of the loess. Loess exists in the vicinity and rests on the till, as may be seen in a railway cut between these pits and Sheldon (page 131).	4
1.	Sand and gravel horizon. This gravel is fine-grained with a few cobbles, and some of the sand layers show inclined laminæ. The material of the layers changes horizontally in short distances so that any section taken fits only that particular place. The base was not exposed at the pit face but part of the floor of the pit is a cemented zone of cross-bedded sand, probably at the base of the gravel horizon.	10

In a small pit just north of the large abandoned pit, the gravel rests on unleached brownish yellow till that may be either Kansan or Iowan. A pit on the east side of the railway showed 12 feet of fine gravel. Several clay-balls (till) were found here, this being one of the few places where they were seen in the valley gravels. This is within the Iowan region and the gravels may have been carried only a short distance before deposition.

Southwest of Sheldon, Floyd river has a broad, open valley with a gradually widening valley flat. Patches of terrace about 10 feet above the flood plain exist at many places, and there are gravel pits in these terraces at Hospers, two miles north of Alton, at Alton, Seney and LeMars (Plate I). At the east end of the Chicago & North Western railway bridge at Alton some pits expose 10 feet of gravel with thin layers of coarse sand, overlain by three feet of loesslike clay, which rises to an indistinct bench 20 feet above the river. Other pits in a bench of similar height north of the railway station show the same loesslike zone overlying the gravel.

A pit near the river in the northwest part of LeMars showed the following section:[49]

		Feet
5.	Soil, sandy, black	4
4.	Loesslike clay, leached	3½
3.	Loesslike clay, unleached, with thin layers of sand. The upper part of this zone contains small calcareous concretions.	6½
2.	Gravel	3
1.	Sand with thin layers of silty sand	3

The calcareous material removed by leaching from zone number 4 has been concentrated in the upper part of zone number 3 in the form of con-

[49] This or a pit nearby was described and figured by H. F. Bain in his report on Plymouth county. Iowa Geol. Survey, Vol. VIII, p. 338 and Plate 29, figure 2.

cretions. These two zones are the time equivalent of the loess of the upland and togther form a horizon much thicker here than farther up the Floyd valley at Sheldon. From the pit of B. Erdman just west of the above several limb bones and pieces of deer horns have been taken.

South of LeMars the flat of the Floyd valley is a mile to a mile and a half wide, but it is all essentially at flood-plain level. This flat is probably underlain with gravel.

The Floyd river valley contains gravels from its headwaters to its mouth. In the Iowan area above Sheldon these should be of Iowan age and those farther down the valley may also have been derived from the Iowan area. However, tributary valleys which could not have received Iowan drainage, as the West Fork of Floyd river and Deep creek, contain similar gravels and if these latter were derived by the erosion of the Kansan till, then some of those in the main valley may have been derived from the Kansan.

Deep Creek Valley

At LeMars Floyd river is joined by Deep creek, which rises in southwestern O'Brien and southeastern Sioux counties and flows south to Remsen and thence west to Floyd river. Fresh sand and fine gravel appear in benches along this creek, and exposures were seen in every section from Remsen to LeMars. The gravel horizon is overlain by yellow loesslike clay, as in the Floyd river valley.

In the northwest quarter of section 5, Marion township, the terrace is 30 feet above the creek, and a well on the terrace goes 45 feet into sand, or 15 feet below the stream level, without reaching the bottom of the sand. A pit in the northeast quarter of section 4, Marion township, one mile east of Oyens, operated by C. H. Grimes, showed the following section.

	Feet
4. Loesslike clay, leached	3
3. Loesslike clay, unleached, with a few bands of pebbles in the basal part	3
2. Gravel	3
1. Sand and gravel; above water level	6

The pit was worked by a suction-dredge to a depth of about 20 feet below water level. The material is sand and fine gravel with some cobbles. Several vertebræ and other bone fragments have been pumped up with the gravel.

In the lower course of Deep creek valley just northeast of LeMars there are two pits from which gravel has been dredged beneath water level. One is located in the northeast quarter of section 10 and the other a mile farther west in the northeast quarter of section 9. The pit in section 10, now abandoned, showed the following exposure above water level.

		Feet
4.	Soil, passing downward into yellow, sandy clay	6
3.	Alternating layers of fine sand and clayey sand, horizontally bedded and laminated	4
2.	Loesslike clay, brownish, with thin partings of sand What are apparently rootlet impressions penetrate this clay, and iron-staining has taken place along these openings.	6
1.	Gravel, fresh, fine-grained, with a few cobbles 4 to 8 inches through; above water level	10

This pit can be worked to a depth of 47 feet below water level, where a layer is struck that is said to consist of flat, slabby pebbles, too hard to be penetrated by the dredge scoop. The material from this pit is fine sand with very little gravel. Details of stratification are of course unknown. At a depth of 25 feet a silty layer with stems and vegetable material is passed through. This was penetrated over the entire pit area, which is 50 to 60 yards across.

The pit in the northeast quarter of section 9 shows the following section above water level.

		Feet
4.	Soil, sandy, dark	3
3.	Clay, sandy, dark gray, leached	4
2.	Loesslike clay, unleached, containing thin layers of fine sand This is the usual material overlying the gravels but is here thicker and more sandy than common.	15
1.	Gravel, fine, and sand; above water level	5

Gravel is dredged from this pit to a depth of 30 feet below water level. At this depth a layer of slabby pebbles is struck as in the other pit. Prospect drill-holes have been sunk near by, one of which penetrated 58 feet of gravel below water level. As in the pit farther east, there is, at a depth of 20 to 25 feet, a dark silty layer containing vegetable material.

A number of bones have been dredged up from these pits, but no evidence could be obtained as to the horizon from which they came (page 164). They are not greatly altered and have a more modern appearance than bones from the gravel deposits of western Iowa farther south. Six analyses of pebbles from the gravel deposit of Deep creek valley show an average content of 48 per cent igneous rocks, which is about 11 per cent higher than the average for all analyses made of the valley gravels, indicating a greater wear and transportation.

Deep creek is entirely in the Kansan drift region and the explanation of its thick gravel deposit is a rather difficult problem. The valley in which the gravel lies apparently goes through the glacial drift, at least in part, for an exposure of Cretaceous rock exists near the level of the creek in the southwest part of section 2, less than half a mile up the valley from the abandoned pit in section 10, where the gravel was worked to a depth of more than 40 feet below the creek level. Does this deep valley continue down Floyd river to the Missouri? When was the valley eroded, and when was it filled with gravel? Much more evidence concerning these gravel deposits is required before a satisfactory explanation can be given. From the freshness of the gravels and their relation to the overlying loess, it is believed that they were deposited just before the loess deposition or approximately at the time of the Iowan glacial period.

The Little Sioux River Drainage Basin

The Little Sioux is the largest of the southwestward flowing streams of western Iowa. In common with its chief tributary, the Ocheyedan, it heads on the Wisconsin drift plain, and after passing to the Iowan drift region near Milford in Dickinson county, it flows near the Wisconsin drift margin south to the mouth of Brooke creek, in northwestern Buena Vista county. It received the drainage of the Wisconsin ice front from a point east of Sibley to Storm Lake, a distance of about 100 miles, and at the present time drains more than 1,000 square miles of the Wisconsin drift plain. From the mouth of Brooke creek to Cherokee the Little Sioux crosses the Iowan area and receives important tributaries from this Iowan area from the north. On the whole, it drains more than 1,000 square miles of the Iowan drift region. Southwest of Cherokee the Little Sioux is on the Kansan drift region.

The Headwaters of the Little Sioux above Spencer

The Little Sioux river system above Spencer consists of the Little Sioux proper, the Ocheyedan with its tributary the Little Ocheyedan, and Stony creek, all of which have their upper courses within the Wisconsin drift region. There are gravel deposits at various places along the Little Sioux within the Wisconsin area in Dickinson county, but on the whole they do not form continuous terrace benches.

The Okoboji outlet, which drains the lakes of north-central Dickinson county, joins the Little Sioux southwest of Milford. This course was the outlet of enormous floods of water during the Wisconsin ice epoch and there are great gravel deposits along the outlet and along the Little Sioux to the south. Gravel exposures are found in the valley sides and in pits on the terrace. The thickness of the gravel is 10 to 20 feet and it is coarser and more rusty than is the gravel of most of the deposits that are beyond the reach of the Wisconsin ice drainage. Eight analyses of gravels from the Little Sioux valley between the Wisconsin boundary and Spencer show an average of 41 per cent igneous rocks, which is about 5 per cent higher than the average igneous content of gravels found in valleys that could not have received drainage from the Wisconsin ice.

This gravel area extends as a terrace down the Little Sioux valley to the county line and south to Spencer. At Milford the terrace is 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

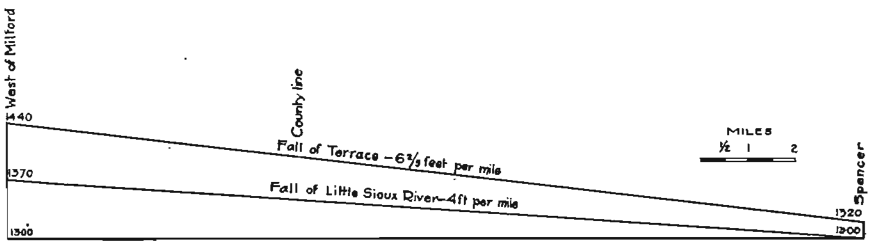

FIG. 19.—Profiles along the Little Sioux river valley from west of Milford to Spencer, showing the gradient of the river and the gradient of the terrace. The distance is measured along the central line of the gravel-filled area.

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

In the pits south of Milford the gravel is overlain by two to three feet of brown sandy, noncalcareous material with few pebbles. It is not the usual leached loess but bears some resemblance to it and, considering the location of the region, where the loess is almost absent on the upland, this may be the equivalent of the loess. Such an interpretation of the overlying material would make the gravel of the Milford bench pre-Wisconsin and place it with the valley gravels of the Iowan age. The more rusty character of the gravel, the location of the deposit with respect to the Wisconsin drift boundary, and the decline of the bench southward to stream level at Spencer seem to separate this gravel deposit from the usual valley gravels and it is most probably Wisconsin outwash. Gravels underlie the valley flats of Ocheyedan river and Stony creek, both of which head within the Wisconsin area and extend out onto the Iowan area to the south, but these flats are low, being little if any above the flood-plain level.

The valley flats of the Ocheyedan, Stony creek and the Little Sioux all unite in Riverton township west of Spencer in a large gravel area (Spencer flat) which extends from Everly eastward through Spencer to the southward bend of the Little Sioux southwest of Dickens. It covers the north half of Riverton township, a strip about two miles wide across Sioux township, and continues west and north up the Ocheyedan and Little Sioux valleys. About half of this area is a terrace 15 to 20 feet above the river. Gravel exposures appear at many places. At the pit of the Spencer Cement Tile Company, the gravel is worked to a depth of about 20 feet by a suction-dredge which pumps the gravel from beneath ground water level. About 10 feet of material is exposed above water level, and this consists of cross-bedded fine gravel and sand. Blue clay is said to underlie the gravel, and bowlders have been encountered toward the base of the gravel. The gravel is overlain by a brown sandy material similar to that over the gravel at Milford.

Tributaries of the Little Sioux from the Wisconsin Drift Region

From Spencer to the mouth of Brooke creek in the northwest part of Buena Vista county the Wisconsin boundary is along or near the east bluff of the Little Sioux and in this distance the valley must have received drainage from the Wisconsin ice.

East of Spencer the Little Sioux is joined by Meadow brook, which with its several branches drains those parts of northeastern Clay and southeastern Dickinson counties which lie within the Wisconsin drift boundary. Small gravel deposits are present along this creek at many places in the Wisconsin region but not in quantities sufficient to form terraces. Five miles east of Spencer the Little Sioux is joined by the outlet of Lost Island lake (Dickens outlet), and there are important gravel deposits along this valley south and southeast of Dickens.

Through southeastern Clay county and northern Buena Vista county west as far as Linn Grove no tributaries of importance enter from the east. Elk creek, entering at Gillett Grove in southeastern Clay county, has very little gravel along its course, although it drained about six miles of the Wisconsin ice margin and now drains probably a township of Wisconsin drift plain. Brooke creek, which flows north along the Wisconsin drift margin to the Little Sioux, drained 18 miles of the Wisconsin ice margin. It has little gravel in its upper course, in Washington and Elk townships, but in its lower course, in Brooke township, there are thick gravel deposits into which the creek and its tributaries have cut deep, narrow valleys. All these tributaries from the east between Spencer and Brooke creek drain the Wisconsin region.

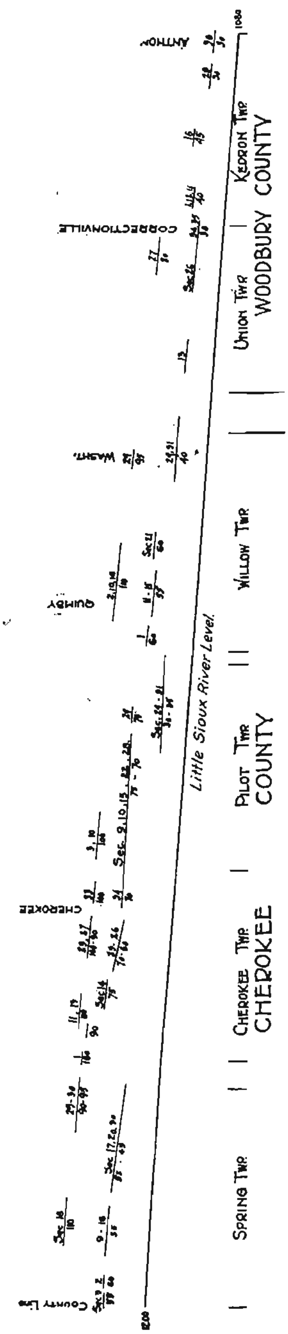

FIG. 20.—Sketch showing altitude of benches along the Little Sioux river valley from the north line of Cherokee county to Anthon in Woodbury county. The figures above the lines are section numbers and the townships are given at the base. The figures below the lines show height above Little Sioux river.

Gravels of the Little Sioux Valley from Spencer to Its Mouth

From the bend east of Spencer south to Gillett Grove, Little Sioux river flows through a narrow valley and there are practically no gravel deposits. Below Gillett Grove, in Herdland township, there are some small gravel terraces, chiefly along the east slope of the valley, which here marks the Wisconsin drift margin. At Sioux Rapids the station of the Minneapolis and St. Louis Railway is on a bench about 50 feet above the river and a gravel pit just north of the railway station shows 20 feet of gravel. To the west there are benches at several places, usually on the inner side of the great bends of the valley. There are in places one, in places two, and in places three benches, and their altitudes above the river differ greatly. One common elevation is 45 to 60 feet above the river. All these benches are probably composed of Wisconsin gravels derived from the Wisconsin ice front, which lay just to the east.

From the mouth of Brooke creek to Cherokee the course of the Little Sioux is across the Iowan drift region. At the bend of the Little Sioux in southeastern O'Brien county, at the mouth of Waterman creek, there are gravel benches about 115 feet above the river, and only 15 to 25 feet below the adjoining upland. A gravel deposit at this level on the west line of section 23, Waterman township, has a thickness of 30 feet. This terrace continues up Waterman creek valley to the north and up Murry creek valley to Sutherland but is not present along the Little Sioux valley to the east. This is in accord with the interpretation given elsewhere[50] that

50 Iowa Geol. Survey, Vol. XXVI, pp. 313-318, 1917.

the Little Sioux river came into its present course across the great divide in Wisconsin time and that Waterman creek is the northward continuation of the pre-Wisconsin Little Sioux.

South of the bend and in Cherokee county two bench levels are common; one near the upland, 100 to 120 feet above the river, and another 50 to 55 feet above the river. The elevations of these benches along the Little Sioux valley across Cherokee and Woodbury counties are shown in figure 20. In Spring township the higher terrace is found on the north line of section 2, in the southeast quarter of section 17, in the west half of section 29, and at the lower ends of the valleys which enter in sections 16 and 19. The lower terrace is found in sections 3, 2, 9, 16 and 29, and as a large area in sections 17, 20 and 30. At many places this terrace grades down to the flood-plain level.

In Cherokee township the higher terrace is found in section 13, along the lower course of Mill creek, and southward to and through Cherokee. Lower terraces of considerable area are found north and south of Cherokee, and the town of Cherokee stands on such an area. There seems to be very little uniformity in the altitude of these benches.

In section 14 there are two pits in the terrace, which is here about 75 feet above the river, that go down into the deposit 50 and 60 feet, respectively. The material is sand and gravel, with a few bowlders. Clay-balls are abundant locally. The material is relatively fresh but oxidized. The pit of the Cherokee Sand and Gravel Company was 60 feet deep, and the bottom was on a bowlder zone which is said to rest on "blue clay". About 80 rods south of this pit is the Gilleas pit which showed a face 50 to 60 feet high, made up of layers of coarse and fine gravel and sand. There are many cobbles and small bowlders in this pit, and some very large bowlders. On the basis of the evidence given elsewhere (page 57) that a great lens of till is interbedded with the upper part of this gravel, it is known to have accumulated during the Iowan ice epoch.

Just south of Cherokee in the southwest quarter of section 34 the Illinois Central Railway Company has removed the gravel from an area of several acres. An exposure in the east end of this pit showed till, probably Kansan, below about 20 feet of gravel.

In Pilot township the most continuous terrace is 70 to 75 feet above the river, but other altitudes are represented. At Washta the lower terrace is not over 40 feet above the river, and the upper one is 95 feet above water level (figure 20). At Correctionville the terraces are still lower, being 30 and 80 feet above the river. Correctionville stands on the lower terrace and the higher one is represented by benches at the mouth of, and within the valley of Pierson creek.

The lower terrace is found in Kedron township south of Correctionville, where there is a pit on the west line of section 15; at Anthon, where it is 30 feet above the river; and in sections 17 and 18 of Miller township, three miles south of Anthon. Farther south terraces were not recognized, and practically all of the flat is flood plain, at an elevation of 20 to 25 feet above the river.

The upper bench level was not positively identified south of Correctionville, but masses of gravel were seen at several places high up on the slopes of the valley. In the southwest quarter of section 20, Miller township, there is some oxidized gravel 85 feet above the river; opposite Oto in section 5 there is a gravel deposit about 100 feet above the river; and in section 8 there is an exposure of sand 80 to 90 feet above the river. These materials are all more oxidized than the deposits found north of Correctionville.

Since Little Sioux river drains so large an area of Wisconsin drift, it should have carried much Wisconsin drainage and much gravel along its valley should be of this age. If the course westward across the great watershed is a Wisconsin glacial diversion, then the gravel benches in this part of the valley must be of Wisconsin age. The lower benches across Cherokee and Woodbury counties may be of Wisconsin age. The high bench beginning in southeastern O'Brien county and continuing southward is continuous with benches in valleys that did not receive Wisconsin gravels. Also the gravel of this high bench is overlain by loess in the north part of Cherokee (page 127), in the southwest part of section 31, Pilot township, and at a few other places along the Little Sioux valley and at many places along the courses of the tributary valleys. This upper terrace is, therefore, preloess in age and is interpreted as Iowan.

Tributaries of the Little Sioux from the Iowan Drift Region

All the tributary valleys of the Little Sioux from the west, between Spencer and Cherokee, drain the Iowan region and did not receive drainage from the Wisconsin ice, and yet these valleys in Clay, O'Brien and Cherokee counties contain prominent gravel deposits, which continue in some cases to the heads of small valleys, whether these head northward or to the east or to the west toward some of the interstream divides.

Willow Creek.—The first creek of importance which joins the Little Sioux from the west, south of Spencer, is Willow creek. Along its lower course in section 7, Herdland township, O'Brien county, there is a fresh gravel deposit covering a large area and forming benches about 30 feet above the creek and 35 to 40 feet above Little Sioux river. An analysis of pebbles showed the presence of 72 per cent sedimentary rocks, all of which were limestone. These gravels are too far from the mouth of the valley to have washed back from the Little Sioux and therefore are not of Wisconsin age. They were derived from the Iowan region possibly during the Wisconsin epoch, for the elevation of the bench accords with that in the Little Sioux valley.

Waterman and Murry Creeks.—In its upper course the valley of Waterman creek, which drains eastern O'Brien county, is a broad sag 15 to 20 feet below the general level, but it deepens within a short distance, so that in its lower course it is more than 100 feet below the upland. In western Omega township there is a gravel bench 15 to 20 feet above the valley bottom, and gravel extends down to water level. The altitude of this bench above the stream increases greatly to the south so that in central Grant township it is 70 feet and near the mouth of Waterman creek more than 100 feet above the stream. Here it unites with the high-level bench of the Little Sioux valley. The relation of the slope of the terrace and the gradient of the creek is shown in figure 21. In Grant and Waterman

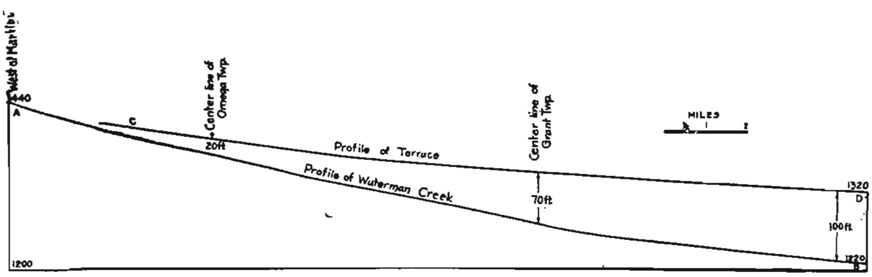

FIG. 21.—Profiles along Waterman creek valley from west of Hartley to its mouth, showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

townships the terraces have considerable area and the gravel in most of them is 20 to 30 feet thick. Waterman creek and its tributaries have cut narrow, steep-sided valleys in the gravel-covered area, leaving level-topped spurs extending out toward the creek from either side and making a very rugged topography. The gravel material is very uniform, consisting of fine gravel with pebbles and small cobbles. The sand is coarse- or medium-grained, subangular, and the larger grains are dominantly limestone and the smaller grains dominantly quartz.

Murry creek is a tributary of Waterman creek. It heads on the east slope of the high divide of O'Brien county, a mile north of Sutherland, and flows south of east to Waterman creek. Its entire length is only about 10 miles. Along its upper course at Sutherland there are several gravel pits exposing 10 to 15 feet of fresh gravel which rests on glacial till and is overlain by two to three feet of loesslike clay (leached loess). At Sutherland the gravel terrace is only 15 feet above the stream, but to the east its altitude increases as the stream descends, until at the mouth of the creek the terrace merges with the high-level benches of the Waterman and Little Sioux valleys at 110 feet above the valley bed. The terrace in this distance drops 100 feet while the stream drops 200 feet. The slope of the terrace and the gradient of the stream are shown in figure 22.

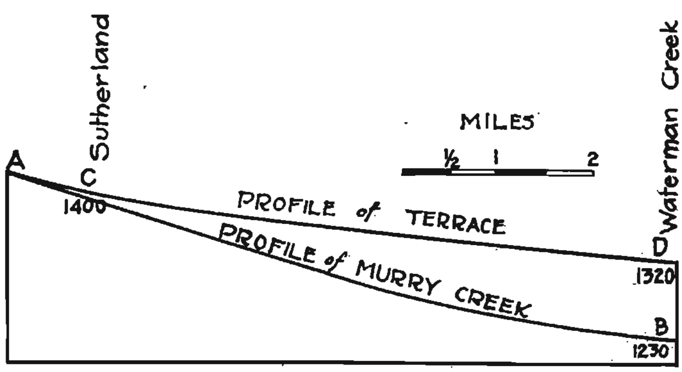

FIG 22.—Profiles along Murry creek valley from Sutherland to its mouth, showing, A—B, the gradient of the creek, and, C—D, the gradient of the terrace.

This valley furnishes one of the best examples of the way the gravels exist in small valleys well out on the upland only a mile or so from the head of the stream. It furnishes very positive evidence against the hypothesis of overwash from the Wisconsin ice margin to the north. The stream heads on a north-south divide and numerous streams flowing to the east and west drain the divide farther north. If water could have passed over the high divide south of Ocheyedan river, it would have been carried away either to the east or west by some one of a dozen valleys to the north of Sutherland. The altitude of the gravels at Sutherland is 1415 to 1420 feet above sea level. They are on the slopes of the highest watershed of northwestern Iowa.

Mill Creek.—Mill creek, with its tributaries, drains central and southern O'Brien county and central northern Cherokee county. The territory which it drains in its upper part is quite level but farther south its basin is more rolling, and in northern Cherokee county it is rather rugged. Mill creek did not receive drainage from the Wisconsin ice, for its headwaters are all south of the high divide of southern Osceola county and their gathering grounds are limited on the north by the headwaters of Floyd river and Waterman creek. However, the valleys of Mill creek and its tributaries contain gravel, which in many cases extends nearly to their heads on the upland. This applies to creeks heading east and west on the intervalley divides as well as to those heading northward.

Three miles west of Primghar several branches of Mill creek unite, and at their union there is an almost level area covering several square miles which appears to be underlain with gravel. The area is not absolutely flat but rises gradually away from the creek and its boundary is in some places quite indefinite. It has an altitude of about 15 feet above the creek but is not a definite terrace. Projections of this area extend up stream courses to the northwest, north and northeast, and it continues south beyond the center of Dale township. Wells near the quarter-corners on the south of section 33 and the east of section 32, Summit township, are 20 feet deep in sand and gravel and one at the quarter-corner on the south of 29 is said to be 40 feet deep and all in gravel.

An east branch of Mill creek heads about two miles northeast of Primghar and flows southwest through northwestern Highland and eastern Dale townships. In sections 6 and 7 of Highland township, only a few miles from its head, this valley contains a gravel deposit with distinct benches 15 feet above the creek. Two gravel pits in these benches show seven to eight feet of fine gravel and sand, overlain by two to four feet of leached loesslike clay. The stream has cut through the gravel, exposing the till beneath. Benches are found farther down the valley through Dale township, as in the southwest corner of section 13 and at the northwest corner of section 26.

Near Paullina in Union township the benches are 20 to 25 feet above Mill creek, and there are numerous exposures of gravel along the main valley and in the lower courses of tributaries. The gradient of Mill creek is greater than the slope of the terrace level and the elevation of the benches above the creek increases southward as shown in figure 23.

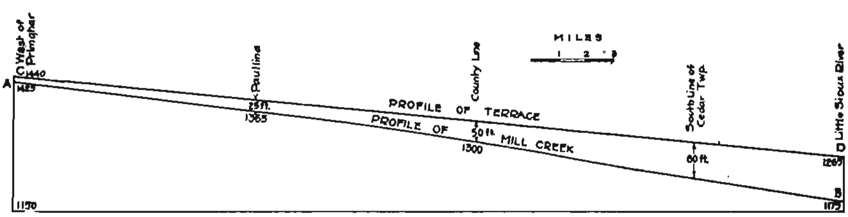

FIG. 23.—Profiles along Mill creek valley from central O'Brien county to its mouth showing, A—B, the gradient of the stream, and, C—D, the gradient of the terrace.

In section 28, Union township, there is a large exposure in a bench 40 to 45 feet above the stream. In part of the exposure the gravel apparently extends to the water level, but elsewhere it is underlain by about 10 feet of indefinite gray to brown silt or clay which rests on brownish yellow till, apparently Kansan. This clay material is probably the Loveland horizon. The gravel here is fresh fine gravel with much sand and is overlain by three to four feet of loesslike clay. On the south side of the valley in the west part of section 34 the bench is about 50 feet above the creek (figure 23). The gravel horizon consists of 35 to 40 feet of fresh coarse sand with pebbles and cobbles scattered through it. It is overlain by four to six feet of loesslike clay and overlies till which rises six feet above the stream.

Willow and Nelson creeks head in Liberty township north of Calumet, flow westward into Union township, turn southward, unite, and join Mill creek just beyond the county line. Willow creek has a number of gravel hills along its slopes in Liberty township (pages 93 to 96), but it does not have a prominent valley-gravel deposit. Below the turn to the south in eastern Union township gravel benches are common along these creeks, especially in sections 25, 26 and 36. On the south line of section 24 a pit shows five feet of very fresh fine gravel, and a well on the bench along Nelson creek in the southwest quarter of section 23 penetrated 20 feet of sand and gravel. A low area connects Nelson creek valley in the west part of section 23 with Mill creek valley in the south part of section 15. It suggests an old water course, but the surface is undulating and does not appear to be underlain with gravel.

Farther south in Cherokee county the quantity of gravel material along Mill creek is larger, although the benches have small areal extent and are by no means continuous. The original width of the aggraded flat, as shown in figure 24, was about one mile, but much of this area has been cut out and is now in steep slopes or narrow flood plain. The altitude of the benches above the creek increases southward (figure 23), so that on the south line of Cedar township they are 75 to 80 feet above the creek and near the mouth of the valley they stand almost 100 feet above the stream. The creek winds back and forth from side to side of the valley, undercutting first one bank and then the other, and the gravel areas on the inner curves of the creek are found successively on alternate sides along the valley.

The Mill creek bench extends into the lower course of a tributary valley in the northeast quarter of section 10 and the east half of section 3, Cherokee township, and from this valley a prong of the bench extends southeast across the northwest quarter of section 11 to the Little Sioux bench (figure 24). At the time of maximum aggradation this prong separated an area of upland in the southwest part of section 11 and the northwest part of section 14 from the upland to the north.

Minor Tributaries in Cherokee County.—In section 11, Spring township, in the northeast corner of Cherokee county, a small creek enters the

Little Sioux from the east, and in the northwest quarter of section 12 there are benches along this valley 105 to 110 feet above the creek. The material exposed is relatively fresh sand with pebbles, has a thickness of

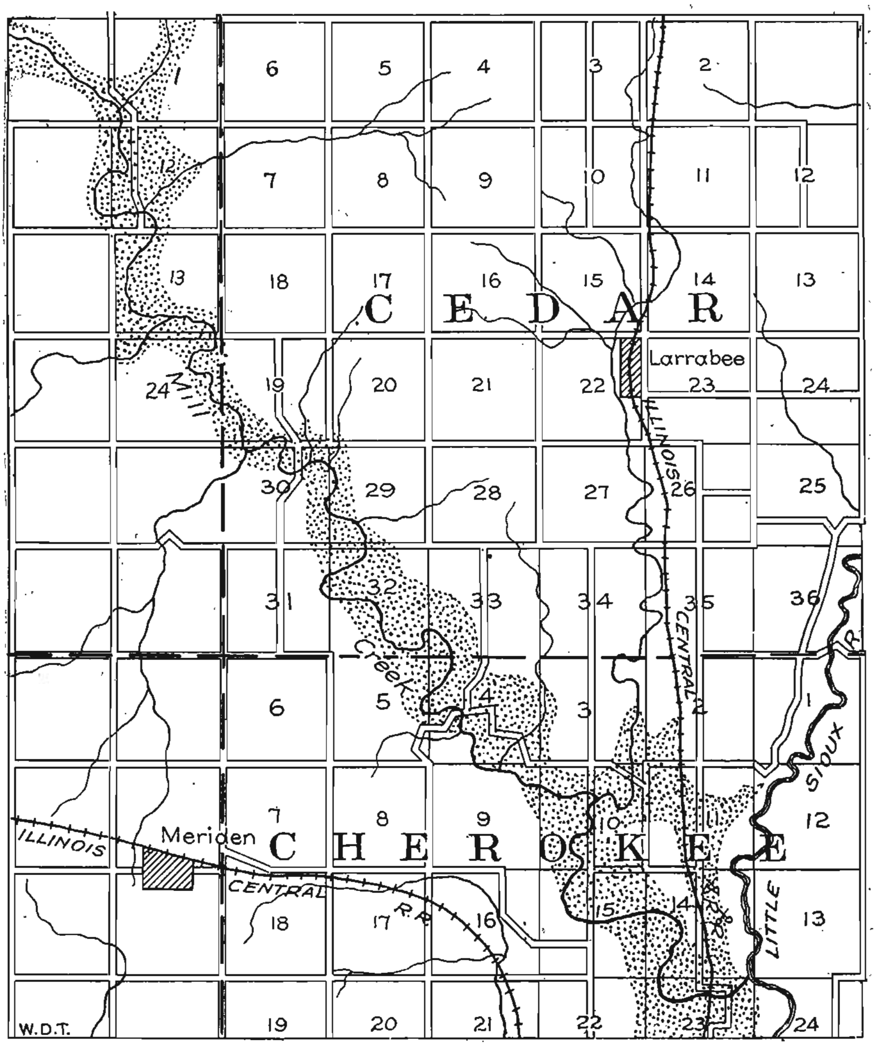

FIG. 24.—Map of a part of northern Cherokee county showing by the shaded area the original extent of the aggraded flat of Mill creek. Part of this area remains as terrace and part has been cut out and now exists as steep slopes or flood plain.

10 to 20 feet, and rests on till. A thin layer of gravel was seen on the slope of this valley near its head two miles farther east, in the northeast quarter of section 7, Brooke township, Buena Vista county.

Most of the east half of section 16, Spring township, is a terrace 110 feet above the Little Sioux, and a projection of this extends east up a valley through section 15. The creek flowing southward through sections 18 and 19 of Spring township is bordered by benches 65 feet above the creek, and the gravel, which is 20 to 30 feet thick, rests on till. Gravel benches exist also along the valley in sections 24 and 25, Cedar township, especially in its lower part, where they become continuous with the bench of the Little Sioux valley. In Cherokee township there are gravel deposits in tributary valleys in sections 1 and 13.

In Pilot township two small creek valleys from the east contain notable gravel and silt deposits. One of these is in sections 10 and 11 and the other in the north parts of sections 22 and 23. The higher terrace of the Little Sioux valley continues into the lower end of the valley in section 10 and is represented in this valley by gravel benches almost to the township corner. In most of the exposures the material is clean fine gravel and quartz sand, but at some places deposits of silty sand and iron-stained silty material are present. In the lower part of the valley the gravel and silt deposit rests on Nebraskan till, but in the upper course of the valley it rests on Kansan till.

The higher bench of the Little Sioux valley also extends into the mouth of the tributary valley in the north part of section 22 and is marked by small benches on the valley sides eastward beyond the central line of section 23. At the mouth of the valley the terrace is 80 feet above the creek, but the gradient of the creek bed is so great that a mile east the benches are only 15 feet above the stream. In this distance the terrace rises 25 feet but the creek rises 90 feet. Where the valley crosses the quarter-section line of section 23 the gravel rests on Kansan till, which in turn rests on Nebraskan till, but farther down the valley the Kansan till is absent and the valley-filling rests on the Nebraskan.

These two valleys of Pilot township are just outside the Iowan drift region but received Iowan drainage. Because of the bearing of the deposits in the valleys on the question of the location of the Iowan boundary they were fully discussed on pages 72 to 77.

All the tributaries of the Little Sioux from the west between Spencer and Cherokee and the minor tributaries from the east in northeastern Cherokee county drain the Iowan drift region, and the gravels are interpreted as outwash from the Iowan ice sheet, collected into the valleys which had been but slightly modified by the thin veneer of Iowan drift. In some places, as in the bluffs of Mill creek in section 14 of Cherokee township north of Cherokee (pages 84 to 87) and in the gravel pits of the same section (page 57), the gravels are interbedded with the till, showing an oscillation of the edge of the ice sheet during the time of gravel accumulation. Mill creek and Waterman creek furnish the greatest examples of gravel deposits in the Iowan drift region.

Tributaries of the Little Sioux in the Kansan Drift Region

Through Cherokee and Woodbury counties, outside the Iowan boundary, there are many small valleys, tributary to the Little Sioux, that have gravel in their lower courses. In general the benches of these valleys are continuous with those of the Little Sioux valley. In some cases the gravel may have been carried into the tributary valleys from the main valley, but in most cases it continues too far up the tributary valleys to have been derived in this way.

In Cherokee township there are gravel deposits in the valley from the northwest at Cherokee as far up as the central part of section 21 and in the valley which enters from the northwest just south of Cherokee. The higher bench of the Little Sioux valley continues into both of these valleys. These two small valleys are not far beyond the Iowan drift boundary as mapped, and there are some exposures in section 28 (page 129), suggesting that the Iowan ice sheet may have crossed Mill creek and occupied the central part of Cherokee township. Such an extension would account for the gravels of these two valleys as Iowan. However, there are other valley gravels in the Kansan region farther southwest which could not have been supplied by any possible extension of the Iowan region.

In the lower course of Parry creek, which drains the western part of Pilot township, there are a few benches high up on the slopes about 70 feet above the creek and about 35 feet above the lower terrace in the Little Sioux valley. Benches are found at intervals farther up the valley. Rock creek, which joins the Little Sioux north of the center of Willow township, also has along its lower course benches which are continuous with high, narrow benches along the Little Sioux valley to the north and south. These are present at intervals up the valley to the center of Rock township and decrease in altitude until they are only 15 feet above the creek.

Opposite Correctionville, in northeastern Woodbury county, the high-level bench of the Little Sioux valley, 80 feet above the river, continues into the lower end of Pierson creek valley. A gravel pit in this bench at the northwest corner of section 34, Union township, at the mouth of the valley, showed 23 feet of fine-grained gravel and sand. The Walsh Brothers' pit near the center of the southeast quarter of section 28, half a mile within the valley, showed 25 feet of gravel overlain by four feet of fine sand and above this about three feet of leached loess. An abandoned pit at the center of section 20, three miles within the valley, showed 10 feet of gravel over blue Kansan till and overlain by three to five feet of sand and sandy clay. Benches of gravel continue up the west branch of the creek to Pierson and are present in the lower course of the north branch. The material exposed in these pits is almost entirely clean quartz sand and fine gravel and is more worn than are the valley gravels farther north. Four analyses of pebbles from this valley show an average of 47 per cent igneous rocks, which is 10 per cent higher than the average of all valley gravels, and the sand averages about 95 per cent quartz grains. There are small snail shells in the gravel, and the pits in sections 34 and 28 have yielded some vertebrate remains (page 165).

The material overlying the gravel of the benches in the lower course of Pierson creek valley is not usually distinctive loess, but leached loess overlies the gravel at the Walsh pit and the sand and sandy clay of other exposures is undoubtedly the time equivalent of the loess. The stratigraphical position of the gravel below the loess is well shown on the north line of section 20 where a gully on the west slope of the north branch of the creek shows seven feet of loess, the upper three feet of which is leached, overlying 20 feet of gravel. The continuity of this gravel with that farther down the valley cannot be questioned, as this exposure is only half a mile from the pit exposure of section 20.

These tributary valleys south of Cherokee are entirely in the Kansan drift region and such deposits as they contain must have been derived from the Kansan drift. The gravels and the benches of these valleys are continuous with those of the Little Sioux valley and apparently were deposited at the same time.

Maple River Drainage Basin

Maple river heads in northeastern Cherokee county and flows southward through eastern Cherokee and Ida counties to Ida Grove. Here it changes direction to southwest and holds this course to its union with the Little Sioux southeast of Onawa. In eastern Cherokee county this river has a broad upland valley with a large flat, much of which is overflowed by the river at times of high water. In northeastern Ida county the valley becomes deeper where it enters the more rugged part of the Kansan drift region and from here southward it is a broad, open valley more than 100 feet deep.

The broad valley of Maple river through eastern Cherokee county probably is underlain with gravel material, but the river has only a shallow channel and gravel was seen at only a few places. In Galva township of northeastern Ida county, gravel was seen in benches at the northwest corner of section 10 and in sections 22, 27 and 34. The valley joining Maple river valley at Galva is bordered by gravel benches through the north part of section 23, and a pit just north of Galva shows 10 feet of clean gravel and sand overlain by five feet of yellow loesslike clay or leached loess.

At Ida Grove, Maple river is joined by Odebolt creek from the east. On the south side of the latter, in the west part of section 19, Blain township, there is an exposure of about 15 feet of sand with a few pebbles, and there is an abandoned gravel pit just northeast of the railway station at Ida Grove.

The headwaters of Maple river are entirely within the Iowan drift region and separated from the Wisconsin drift region by the high north-south divide of western Buena Vista county. No Wisconsin drainage could possibly have entered the valley. From section 20, Pitcher township, Cherokee county, to Galva in northeastern Ida county, a distance of 13 miles, the Iowan boundary is mapped along the east side of Maple river. From Galva to Ida Grove the valley is out in the Kansan region, but its tributaries from the east head in the Iowan region. Southwest of Ida Grove the basin is entirely in the Kansan region. The gravels of the Maple river basin are, therefore, assigned to the Iowan outwash in large part. The gravels in some tributary valleys southwest of Ida Grove, which drain only the Kansan region, must have been derived from the Kansan.

Boyer River Drainage Basin

Boyer river heads southwest of Storm lake in southern Buena Vista county and flows east of south to southern Sac county. In this portion of its course it is four to six miles west of the Wisconsin drift margin and received drainage from the Wisconsin ice by a break through the divide to the east just north of the Buena Vista-Sac county line and by the Wall lake outlet south of the town of Wall Lake. From southern Sac county, Boyer river flows southwest across Crawford and Harrison counties to Missouri river.

The headwaters of Boyer river above Early occupy broad, upland valleys, characteristic of the Iowan drift region. Flat areas, that apparently are underlain with gravel, are found along the valleys of Eden township, but the streams have cut only shallow channels into them and exposures are few. In Boyer Valley and Clinton townships the valley is deeper. Gravel deposits were seen at a few places and may be of either Iowan or Wisconsin age. In southern Clinton and northern Levey townships, near the Iowan boundary, the valley contains gravel benches, probably of Iowan gravels.

The Wall lake outlet connects the Boyer valley with the Wisconsin plain and with a great gravel deposit of Wisconsin age at the west end of Wall lake. The bottom of the outlet is a swampy flat, projections of which extend up small tributaries of the Boyer into northwest Levey township.

Southwest of the Wall lake outlet, across Crawford county, the Boyer valley has steep slopes and a flat bottom which is at flood-plain level, and is in most places one-half to one mile wide. At a few places, especially at the mouths of tributary valleys, there are benches that look like remnants of a former valley filling.

In a recent report on the Geology of Crawford county,[51] Doctor Lees shows that gravels have a wide distribution in the valleys of Crawford county (pp. 328-338 and map, p. 362). They are present on the lower slopes of the valleys where they at places form benches and they exist over the upper slopes at places even to the upland level. They are on the slopes of a topography which is cut into the Kansan drift and are overlain by the loess mantle. As in the region farther north, they are present both in the large valleys that cross the county and carried drainage from the Iowan drift region, such as the Boyer valley, and in many of the smaller valleys that head out on the divides of the Kansan region. Their presence in these smaller valleys which are entirely in the Kansan region far beyond the Iowan boundary gives further evidence that the valley gravels were in part derived by the erosion of the Kansan till, as discussed on pages 168 to 170.

FOSSILS FROM THE VALLEY GRAVELS

The valley gravels, especially in the southern part of the area, have yielded some fossil remains. These include both vertebrates and mollusks.

The two deep pits just northeast of LeMars (pages 147 to 148) have yielded a number of bones. They were brought up by the dredge scoop and are said to come from different depths. Among the material from these pits are elephant tusks and teeth, part of a pelvic girdle of an elephant, deer horns, horse teeth and a number of unidentified

[51] Iowa Geol. Survey, Vol. XXXII, pp. 241-362, 1927.

leg bones and vertebræ. Remains, chiefly deer horns, limb bones and vertebræ have been obtained also from the Erdman pit in the Floyd river valley in the northwest part of LeMars (page 147) and from the pit operated by C. H. Grimes in Deep creek valley one mile east of Oyens (page 147).

From the pit of the Cherokee Sand and Gravel Company north of Cherokee a tooth of *Elephas columbi,* an elephant tusk, and various small bone fragments have been taken.

Two specimens obtained from the pit of the Walsh Brothers in Pierson creek valley west of Correctionville were identified by Dr. O. P. Hay[52] as "a horn core and the base of a skull of a bison, both belonging to *Bison occidentalis.*" The writer examined a large proboscidian tooth, a horn core, a horse tooth and some pieces of unidentified bones which were taken from the gravel pit of Paul Fleming, at the mouth of Pierson creek valley. A few miles south of Correctionville, within the Little Sioux valley, is the Gilleas gravel pit, from which a "buffalo head", deer horns, a worn tooth of *Elephas primigenius* and various bone fragments have been taken.

Some proboscidian bones have been found in the gravel deposit of Rock river at Rock Rapids. This locality is well out in the Kansan drift area, but the valley carried both Iowan and Wisconsin drainage.

The bones found in the gravels of northwestern Iowa are, so far as known, all isolated finds and many of the bones are worn. No complete skeletons have been found. The evidence is not such as to prove that the animals lived while the gravel was accumulating, although probably this was true.

Small snail shells were found in the gravel at several places in the southern part of the area, mostly in the tributary valleys of the Little Sioux at or near their union with the main valley. They were found in coarse sand and fine gravel as well as in silty sand and silt deposits.

In the creek valley in the northeast quarter of section 11, Pilot township, Cherokee county, gastropod shells were found in fresh coarse sand in a railway cut. In the next creek valley to the south, in the northeast quarter of section 22, small gastropod shells were found in a compact silt that forms part of the valley filling.

The gravel in the Paul Fleming pit at the mouth of Pierson creek, opposite Correctionville, contains many snail shells. At least five spe-

52 Iowa Geol. Survey, Vol. XXIII, p. 74, 1914.

cies were collected here, although most of the shells belonged to one species.

South of our area, in Crawford county, shell-bearing gravels were found in two tributary valleys of the Boyer. Along Porter creek in Stockholm township, north of the village of Boyer, there is a gravel deposit which forms benches 30 to 40 feet above the creek, and snail shells were found at several places in the fresh sand and fine gravel in these benches. At the lower end of the valley just southwest of Boyer, mussel shells (unios) were found in a brownish yellow to blue-gray silt zone. Farther south in the southwest part of section 6, Washington township, just above the mouth of the valley of Buck creek, which joins the Boyer near Arion, there is a bed of fresh, clean gravel which contains many gastropod shells. The zone is part of a 30-foot bank of sand and gravel which is overlain by fossiliferous loess.

All the gravels containing molluscan fossils and practically all those containing vertebrates lie outside the Iowan drift area. None of the gravels of the northern part of our area are fossiliferous. The deposits along Mill creek and elsewhere were examined carefully for fossils but none was found. South of Cherokee within two miles of the Iowan drift boundary fossiliferous gravels were found and at many places to the south. The gravels deposited by the waters flowing out from the Wisconsin ice sheet and the Iowan gravels deposited within the Iowan drift area evidently accumulated under conditions unfavorable for the gastropod fauna.

ORIGIN AND AGE OF THE VALLEY GRAVELS

The term valley gravels is intended particularly for those gravels which occupy valleys in the Iowan drift area and are of Iowan age. In those valleys of the Iowan area that head back into the Wisconsin drift region and which, therefore, carried drainage from the Wisconsin ice front, there may also be gravels of Wisconsin age, but it was not possible in most cases to distinguish the two types. Further, there are similar gravels in many valleys of the Kansan drift region which could not have been reached by drainage from the Iowan or the Wisconsin ice sheets and which, therefore, must have originated in some manner within the Kansan area. In the above discussion of the distribution of the gravels, all gravels occupying valleys have been treated, and in most of those cases in which valleys must have received drainage from two ice sheets it was not possible to differentiate the gravels of different ages.

In the Iowan drift region most of the gravels probably rest on Iowan till, although it is not as a rule possible to distinguish this till from the Kansan. In the valleys of the Kansan drift area the gravels rest on the Kansan till, except where the Kansan till had been entirely removed at the time of gravel deposition, as in the Little Sioux valley and the lower courses of some of its tributaries, in which case they rest on the Nebraskan till.

In composition the gravels are like those of the clay-ball hills (pages 90 to 102) and the inclosed gravel masses (pages 111 to 115) and closely resemble the pebbles that may be picked from the Iowan and Kansan tills. Clay-balls and shale pebbles are not common, as they are in the gravels of the gravel hills, indicating that the valley gravels were subjected to some transportation; and yet they were not transported far enough to wear out the limestones or to round the pebbles, most of which are subangular. Masses of Iowan till included in some of the gravel deposits, as in the gravel pits north of Cherokee (page 57), show that in these cases the Iowan ice was near. The composition is distinctly against an interglacial age.

The gravels of both the Iowan and the Kansan drift regions are generally overlain by pebbleless loesslike clay which is continuous with a similar deposit over the upland. In the west and southwest parts of the area studied, this deposit over the upland is the undoubted loess; and over the remainder of the Kansan drift and over the Iowan drift this deposit, although thinner and in many places leached for its entire thickness, is the time equivalent of the loess (page 120). The loesslike clay apparently was deposited soon after the gravels, for the top of the gravel deposit does not show the least indication of a weathered zone. In fact it appears that there was a transition from gravel deposition to deposition of loesslike clay, for there is at many places alternation of the two materials near the contact and a recurrence of sand and pebble bands in the lower 12 to 18 inches of the loesslike clay. The lower part of this loesslike clay shows banding in some exposures and must be water laid. The upper part must be eolian, a method of origin which would accord better with its texture and its general lack of bedding. The gravels apparently were deposited just before the formation of the Peorian loess.

Most of these valley gravels of northwestern Iowa were interpreted as Wisconsin gravels by Macbride and Wilder. At first they were interpreted as being largely within the area of the Wisconsin drift, the boundary of that drift sheet being placed far enough southwest to include O'Brien county. Later, when the Wisconsin drift boundary was shifted to the Ocheyedan-Little Sioux course, the gravels of the extra-morainic region were interpreted as being due to waters which broke over the great divide and flooded the country to the southwest. With the margin located across Sac, Buena Vista, Clay, Dickinson and Osceola counties as described in the report of 1917,[53] it is possible to determine which streams could have received drainage from the Wisconsin ice. These are Big Sioux river; Rock river and its tributary, Little Rock river, with Otter creek; Little Sioux river and its tributary, Ocheyedan river, with the Little Ocheyedan; and Boyer river. The drainage courses of Floyd river, Mill creek, Waterman creek, Maple river and others which contain valley gravels could not have received Wisconsin drainage. Therefore, from the viewpoint of the possible distribution of Wisconsin outwash, the valley gravels could not all be of Wisconsin age.

The great bulk of the valley gravels are here interpreted as of Iowan age, deposited by the waters flowing out from the retreating Iowan ice front. The valleys had not been obliterated by the thin sheet of Iowan till (page 41) and from the beginning were stream courses and sites of deposition for the overloaded glacial waters. Where the waters passed beyond the Iowan drift area and deposited material in the valleys of the Kansan drift area the deposits occupy true erosion valleys and rest on either Kansan or Nebraskan till. This explanation applies to all the gravels in valleys that carried the drainage from the Iowan ice sheet.

The gravels in those valleys of the Kansan area that could not have received drainage from the Iowan ice sheet are more difficult to interpret. In general characteristics they are like those of the Iowan area and are overlain by the same loess deposit. Further, the benches formed by the gravels in those valleys of the Kansan area that did not carry Iowan drainage connect exactly with the benches in the main valleys that did carry Iowan drainage and these latter benches continue up the main valleys into the Iowan area. It appears, therefore,

[53] Iowa Geol. Survey, Vol. XXVI, pp. 255-293, 1917.

that the valley gravels and the resulting benches of the Iowan and the Kansan regions are of the same age.

The only difference of any significance noted for the gravels in those valleys of the Kansan area that did not receive Iowan drainage is that they contain a somewhat larger percentage of the more resistant kinds of pebbles. Thirteen analyses of pebbles from benches in valleys that are entirely in the Kansan drift average 47 per cent igneous rocks, while 42 analyses of pebbles from the valley gravels of the Iowan drift area average only 27 per cent igneous. There is also a larger percentage of the resistant types of sedimentary rocks in the analyses from the Kansan drift region, where quartzites average 7 per cent and cherts 4 per cent, while in the analyses from the Iowan drift area each of these types averages only 1 per cent. The sand likewise contains only the more resistant material, about 95 per cent of it being quartz grains. This all shows a greater amount of transportation and wear for this gravel of the Kansan region.

It is believed that this gravel, in valleys of the Kansan region that were not reached by drainage from the Iowan ice sheet, was derived from the Kansan till, from which it was released by erosion, and that it collected in the valleys as the finer material was carried beyond the region. The conditions under which fresh, unleached gravels would accumulate so widely in erosional valleys are not well understood. They may be climatic and associated with the decreased vegetation and increased erosion of the Iowan ice age, during which, although the ice did not actually cover the region, its climatic effects were strongly felt. This would explain the agreement of bench levels and the continuity of the gravels and overlying loess of the two types of gravels, which indicate that they were being accumulated at the same time. That is, the gravels released by erosion of Kansan till were being deposited in the tributary valleys while the main valleys were being aggraded by Iowan outwash. Of course, if this origin is applicable for those gravels of the valleys of the Kansan region which were not reached by the Iowan drainage, the same origin must hold for some of the gravels in those main valleys of the Kansan region which also carried Iowan drainage.

By this interpretation the accumulation of the gravels came after the uplift of the postulated gumbotil plain and after its erosion to a stage which had removed all remnants of the gumbotil and leached zones.

In the valleys there then accumulated the valley gravels. No leaching of the underlying till took place before the gravels were deposited and no leaching of the gravels took place before the deposition of the overlying loess. The gravels were derived largely from unleached materials and accumulated relatively rapidly, for they are not leached, as is commonly true of gravels that accumulate slowly during an interglacial age. If these gravels were derived from the Kansan till by erosion and removal of the finer material as here outlined, they are remarkably fresh and unaltered for such an origin, since they cannot be distinguished from those of the Iowan region which are interpreted as outwash gravels. Perhaps this gravel accumulation was an incident of the declining stage of a period of more rapid, active erosion of the Kansan region during the Iowan ice age.

CHAPTER VI

ANALYSES OF PEBBLES

During the progress of the work in northwestern Iowa about 200 analyses of pebbles from the several types of gravels were made. The method followed was to count out 100 pebbles just as they came from the gravel, taking all those above one-fourth inch and under two inches in diameter. These were then classified according to certain selected rock types and the percentages of the several types determined, as shown in the following tables.

These analyses were made with the hope that a composition basis might be found for the separation of the several types of gravels, but the analyses from these several types are so similar that they cannot be used for this purpose. The variations within one type are commonly greater than the differences between the averages for the several types. There are, however, a few distinctive characteristics, such as the presence of clay-balls in the gravels of the gravel hills, which can be used with a fair degree of accuracy in the differentiation of certain types of gravels. The study was, on the whole, so inconclusive that the data were not included in the report of 1917. The tabulated analyses are here presented for what value they may have. They should be of some assistance to anyone who contemplates a similar study in this region or elsewhere.

Tables of Analyses of Pebbles

For convenience of comparison the analyses of the several types are brought together here in one section rather than distributed through the report where the several types of gravels are described and interpreted. In the tables which follow, the analyses are grouped according to type of deposit, but a few of the placings are somewhat questionable. A number of the analyses made are not included in the tables because they could not be definitely placed in one of the several types of deposits indicated by the headings of the several tables.

One hundred sixty-two analyses of pebbles are here tabulated. They are grouped in eight tables which represent eight more or less definite types of gravels. The last column of each table gives the average for

TABLE I

Analyses of Pebbles from Till or Gravel within the Wisconsin Region

	Dickinson Co., Diamond Lake Twp., Sec. 36, SW. corner, Road cut.	Dickinson Co., Diamond Lake Twp., Sec. 36, center, Ry. cut.	Clay Co., Freeman Twp., Sec. 7, SE.	Osceola Co., Ocheyedan Twp., Sec. 12, SW. Ocheyedan Mound.	Clay Co., Freeman Twp., Sec. 17, NW. (A kame).	Osceola Co., Ocheyedan Twp., Sec. 4, SW. corner.	Clay Co., Freeman Twp., Sec. 7, SW.	Clay Co., Freeman Twp., Sec. 15, NW.	Clay Co., Freeman Twp., Sec. 18, SE. corner.	Clay Co., Herdland Twp., Sec. 16, SE.	Emmet Co., High Lake Twp., Sec. 28, SW.	Emmet Co., High Lake Twp., Sec. 16, SE.	Buena Vista Co., Brooke Twp., Sec. 24, N. line.	Carroll Co., Grant Twp., Sec. 19, center.	Carroll Co., Carroll Twp., Sec. 15, E. line.	Average, Table I. 15 analyses.
Granite-syenite	13	14	13	24	26	28	17	19	26	20	14	27	18	23	19	20
Diorite-gabbro	2	2	--	8	--	3	2	3	2	--	--	1	6	1	2	2
Basalt	10	5	12	16	5	6	9	14	6	12	15	3	4	6	7	9
Quartz	2	1	3	1	1	2	2	--	1	--	3	4	3	1	2	2
Miscel. igneous	2	4	4	2	--	2	1	--	--	2	--	--	3	--	15	2
Total igneous	29	26	32	51	32	41	31	36	35	34	32	35	34	31	45	35
Quartzite	3	3	10	--	4	--	4	2	6	--	--	--	3	1	2	3
Chert and flint	1	2	--	--	1	2	1	3	1	--	--	3	1	1	1	1
Limestone and dolomite	66	60	55	47	59	50	54	57	57	45	64	57	61	58	40	55
Shale	--	9	--	--	1	5	--	2	--	1	--	1	1	5	5	2
Sandstone	1	--	3	--	--	--	--	--	--	--	--	--	--	--	1	0
Clay-balls	--	--	--	--	--	--	9	--	--	17	--	--	--	1	3	2
Miscel. sedimentary	--	--	--	2	3	2	1	--	1	3	4	4	--	3	3	2
Total sedimentary	71	74	68	49	68	59	69	64	65	66	68	65	66	69	55	65

the analyses of that table, using the nearest unit number. Table IX presents a summary of the averages of the eight types represented by the eight tables.

The several rock types selected for the classification are quite general divisions and the determinations were made in the field from the freshly broken pebbles. The granite-syenite division is almost entirely granite but might include any light-colored coarse-grained igneous rock. Likewise the diorite-gabbro division might include any dark-colored fine-grained igneous rocks. The light-colored fine-grained igneous rocks are very rare and are included in the miscellaneous igneous. The quartz pebbles are included in the total igneous. Only an occasional pebble of gneiss or schist was found and these are included with the miscellaneous igneous. The quartzite pebbles are included in the total sedimentary.

The gravels of northwestern Iowa are, in general, quite fresh and unaltered. This is, of course, in keeping with the general freshness of

TABLE II

Analyses of Pebbles from Valley Gravels of the Wisconsin Region

	Dickinson Co., Diamond Lake Twp., Sec. 29, S. Little Sioux valley.	Dickinson Co., Lakeville Twp., Sec. 16, SW. Little Sioux valley.	Dickinson Co., Lakeville Twp., Sec. 21, SW. Little Sioux valley.	Emmet Co., High Lake Twp., Sec. 32, NE. Des Moines Rv. valley.	Palo Alto Co., Walnut Twp., Sec. 9, center. Des Moines Rv. valley.	Palo Alto Co., Emmetsburg Twp., Sec. 25, NW. Des Moines Rv. valley.	Emmet Co., Armstrong Twp., Sec. 15, SE., E. Des Moines Rv. valley.	Emmet Co., Armstrong Twp., Sec. 15, SE., E. Des Moines Rv. valley.	Sac Co., Jackson Twp., Sec. 24, NW. Raccoon Rv. valley.	Sac Co., Jackson Twp., Sec. 24, NW. Raccoon Rv. valley.	Average, Table II. 10 analyses.
Granite-syenite	25	31	23	14	29	23	20	27	37	31	26
Diorite-gabbro	2	1	--	--	1	4	--	1	2	--	1
Basalt	11	--	8	11	13	8	5	4	5	6	7
Quartz	--	2	2	1	--	1	1	1	--	--	1
Miscel. igneous	1	2	--	1	1	1	--	--	2	2	1
Total igneous	39	36	33	27	44	37	26	33	46	39	36
Quartzite	6	1	2	5	8	5	--	--	3	1	3
Chert and flint	--	1	--	--	--	3	1	--	--	--	1
Limestone and dolomite	55	58	65	65	46	53	52	59	50	53	55
Shale	--	4	--	--	--	--	19	2	1	6	3
Sandstone	--	--	--	--	--	1	2	1	--	1	1
Clay-balls	--	--	--	--	--	--	--	--	--	--	0
Miscel. sedimentary	--	--	--	3	2	1	--	5	--	--	1
Total sedimentary	61	64	67	73	56	63	74	67	54	61	64

the tills. In practically all the analyses limestone and dolomite dominate, being about one-half of the whole, and are almost entirely gray compact stone. Other types of sedimentary rocks are not common, sandstone and shale being almost negligible. The second most abundant type is granite, which constitutes about one-fourth of the whole and is dominantly pink in color. Basalt, including greenstone, commonly forms about 10 per cent, and other igneous rocks are not common.

Table I gives the analyses of pebbles from till or gravel within the Wisconsin region. The first three analyses of this table are of pebbles taken directly from the Wisconsin till; the remainder are of pebbles from gravel deposits associated with the till but do not include gravels in valleys. Table II records the analyses from gravels in valleys of the Wisconsin region, and Table III includes the analyses from gravels of probable Wisconsin age in valleys beyond the Wisconsin boundary. Tables I, II and III include all the analyses of grav-

TABLE III.

Analyses of Pebbles from Valley Gravels of Probable Wisconsin Outwash in Valleys Just Beyond the Boundary

	Dickinson Co., Okoboji Twp., Sec. 11, SW.	Dickinson Co., Milford Twp., Sec. 8, NW.	Dickinson Co., Okoboji Twp., Sec. 34, W.	Dickinson Co., Okoboji Twp., Sec. 34, W.	Clay Co., Sioux Twp., Sec. 7, SE.	Clay Co., Sioux Twp., Sec. 7, SE.	Clay Co., Sioux Twp., Sec. 7, SE.	Clay Co., Sioux Twp., Sec. 35, E.	Clay Co., Herdland Twp., Sec. 33, SE. of NW.	Buena Vista Co., Lee Twp., Sec. 5, W. of center.	Buena Vista Co., Lee Twp., Sec. 7, N.	Buena Vista Co., Barnes Twp., Sec. 12, SE.	Buena Vista Co., Barnes Twp., Sec. 12, SE.	Buena Vista Co., Barnes Twp., Sec. 12, SE.	Buena Vista Co., Barnes Twp., Sec. 11, SW. of NE.	Buena Vista Co., Barnes Twp., Sec. 11, SW.	Buena Vista Co., Barnes Twp., Sec. 3, NE. Railway pit.	Buena Vista Co., Barnes Twp., Sec. 3, NE. Railway pit.	Average, Table III. 18 analyses.
Granite-syenite	31	32	40	28	42	21	25	19	25	28	34	21	31	18	33	35	39	28	29
Diorite-gabbro	--	2	--	--	--	1	--	3	--	--	1	3	--	1	1	--	2	2	1
Basalt	8	5	1	5	10	4	12	9	7	8	--	7	5	10	9	13	4	6	7
Quartz	1	1	--	5	3	--	--	--	3	--	2	--	--	--	--	1	1	2	1
Miscel. igneous	1	3	--	4	4	3	4	1	1	3	1	1	--	3	2	--	--	1	2
Total Igneous	41	43	41	42	59	29	41	32	36	39	38	32	36	32	45	49	46	39	40
Quartzite	3	6	2	10	11	5	1	3	--	2	--	--	3	--	--	--	--	--	3
Chert and flint	1	--	2	--	5	3	--	--	1	--	--	--	--	--	--	--	1	--	1
Limestone and dolomite	54	49	51	48	23	61	58	64	62	56	56	59	60	63	52	51	50	61	54
Shale	--	1	4	--	2	2	--	--	1	2	4	9	1	5	3	--	3	--	2
Sandstone	1	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Clay-balls	--	1	--	--	--	--	--	--	--	--	2	--	--	--	--	--	--	--	0
Miscel. sedimentary	--	--	--	--	--	--	--	1	--	1	--	--	--	--	--	--	--	--	0
Total sedimentary	59	57	59	58	41	71	59	68	64	61	62	68	64	68	55	51	54	61	60

els interpreted as Wisconsin in age. The average of the 43 analyses of these three tables is given in column 3a of Table IX. It shows no distinctive differences from the gravels of the Iowan or Kansan regions.

Table IV gives the analyses of the pebbles from the gravel hills of the Iowan region. This type of gravel has a distinguishing characteristic in the abundance of clay-balls or small rounded masses of till.

TABLE IV

Analyses of Pebbles from the Gravel Hills of the Iowan Region

	Nobles Co. (Minn.), Larkin Twp., Sec. 34, NW.	Nobles Co. (Minn.), Westside Twp., Sec. 36, SW.	Nobles Co. (Minn.), Westside Twp., Sec. 36, SW.	Osceola Co., Gilman Twp., Sec. 5, SW.	O'Brien Co., Summit Twp., Sec. 4, SW.	O'Brien Co., Liberty Twp., Sec. 22, NE.	O'Brien Co., Liberty Twp., Sec. 22, NE.	O'Brien Co., Liberty Twp., Sec. 22, NW.	O'Brien Co., Liberty Twp., Sec. 22, NW.	O'Brien Co., Liberty Twp., Sec. 22, NW.	O'Brien Co., Liberty Twp., Sec. 17, SE.	Cherokee Co., Pitcher Twp., Sec. 33, NE.	Cherokee Co., Pitcher Twp., Sec. 33, SE.	Cherokee Co., Cedar Twp., Sec. 10, SE.	Cherokee Co., Cedar Twp., Sec. 10, SE.	Cherokee Co., Cedar Twp., Sec. 26, NW.	Cherokee Co., Cedar Twp., Sec. 26, NW.	Ida Co., Galva Twp., Sec. 15, center of N. line.	Sac Co., Levey Twp., Sec. 1, NE.	Sac. Co., Viola Twp., Sec. 20, SW.	Sac. Co., Clinton Twp., Sec. 35, NW.	Average, Table IV. 21 analyses.
Granite-syenite	22	13	20	16	13	18	17	15	23	18	7	30	22	23	18	18	15	25	21	8	7	18
Diorite-gabbro	--	1	1	2	3	1	--	--	--	--	--	--	8	1	1	--	--	5	--	1	2	1
Basalt	3	8	5	1	5	5	1	2	2	1	1	12	13	6	3	--	3	11	3	3	4	4
Quartz	--	--	1	--	--	--	--	--	--	--	--	4	4	1	1	1	--	4	1	--	--	1
Miscel. igneous	--	1	--	--	1	--	--	--	1	--	--	2	1	--	--	--	--	1	1	--	--	0
Total igneous	25	23	27	19	22	24	18	17	26	19	8	48	48	31	23	19	18	46	26	12	13	24
Quartzite	--	--	--	--	--	--	1	1	--	--	--	7	5	2	1	--	1	7	2	3	3	2
Chert and flint	1	2	--	3	--	--	1	1	2	--	--	2	2	4	2	--	--	3	--	--	1	1
Limestone and dolomite	65	58	64	49	62	75	36	43	55	53	29	39	43	56	65	43	52	37	71	80	80	55
Shale	7	--	5	3	1	--	33	19	--	2	4	--	--	2	6	15	11	--	1	--	--	5
Sandstone	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Clay-balls	2	16	3	25	15	1	11	19	16	26	59	--	2	4	2	23	12	3	--	1	1	12
Miscel. sedimentary	--	1	1	1	--	--	--	--	1	--	--	4	--	1	1	--	6	4	--	4	2	1
Total sedimentary	75	77	73	81	78	76	82	83	74	81	92	52	52	69	77	81	82	54	74	88	87	76

TABLE V, SHEET 1

Analyses of Pebbles from Valley Gravels of the Iowan Region

	Lyon Co., Elgin Twp., Sec. 25, SE. Little Rock Rv.	Osceola Co., East Holman Twp., Sec. 18, NW. Ry. Co. pit.	Osceola Co., East Holman Twp., Sec. 18, NW. City pit.	Osceola Co., East Holman Twp., Sec. 30, NE. Ry. Co. pit.	Osceola Co., Gilman Twp., Sec. 11, center.	Osceola Co., Gilman Twp., Sec. 15, NE. corner. Otter Cr.	O'Brien Co., Floyd Twp., Sec. 21, NW. Floyd Rv.	O'Brien Co., Floyd Twp., Sec. 30, NE. Floyd Rv.	O'Brien Co., Floyd Twp., Sec. 30, center. Floyd Rv.	O'Brien Co., Floyd Twp., Sec. 30. center. Floyd Rv.	O'Brien Co., Highland Twp., Sec. 6, SW.	O'Brien Co., Highland Twp., Sec. 7, NW.	O'Brien Co., Highland Twp., Sec. 7, NW.	O'Brien Co., Union Twp., Sec. 3, S. Paullina Cement Works.	O'Brien Co., Union Twp., Sec. 28, NW. Mill Cr.	O'Brien Co., Union Twp., Sec. 34, W. part. Mill Cr.	O'Brien Co., Liberty Twp., Sec. 20, NE. Willow Cr.	O'Brien Co., Liberty Twp., Sec. 22, NW. Willow Cr.	Cherokee Co., Cherokee Twp., Sec. 5, E. line. Mill Cr.	Cherokee Co., Cherokee Twp., Sec. 3, SW. corner. Mill Cr.	Cherokee Co., Cherokee Twp., Sec. 10, NW. Mill Cr.
Granite-syenite	14	24	17	23	18	21	16	23	14	13	24	15	19	19	16	14	17	17	14	13	17
Diorite-gabbro	3	1	--	3	2	--	1	1	1	1	--	2	1	2	--	3	--	--	4	--	1
Basalt	4	4	6	5	9	10	8	10	4	6	2	5	5	16	8	4	7	4	18	5	12
Quartz	1	--	--	--	1	1	--	2	1	--	2	1	1	--	3	2	1	1	3	1	5
Miscel. igneous	--	--	1	--	--	3	--	--	2	4	--	--	--	--	--	1	--	--	1	--	--
Total igneous	22	29	24	31	30	35	25	36	22	24	28	23	26	37	27	24	25	22	40	19	35
Quartzite	--	--	--	--	--	--	--	1	--	--	1	--	--	--	2	7	--	1	6	2	--
Chert and flint	--	3	3	1	1	1	--	1	2	--	--	1	1	2	--	2	--	--	1	--	--
Limestone and dolomite	78	66	73	68	69	64	75	62	75	68	71	75	72	59	69	59	75	77	53	78	61
Shale	--	2	--	--	--	--	--	--	1	8	--	--	1	--	--	2	--	--	--	--	--
Sandstone	--	--	--	--	--	--	--	--	--	--	--	--	--	--	1	5	--	--	--	--	4
Clay-balls	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Miscel. sedimentary	--	--	--	--	--	--	--	--	--	--	--	1	--	2	1	1	--	--	--	1	--
Total sedimentary	78	71	76	69	70	65	75	64	78	76	72	77	74	63	73	76	75	78	60	81	65

TABLE V, SHEET 2

Analyses of Pebbles from Valley Gravels of the Iowan Region

	Clay Co., Herdland Twp., Sec. 7, center. Willow Cr.	O'Brien Co., Omega Twp., Sec. 18, NE. Waterman Cr.	O'Brien Co., Grant Twp., Sec. 22, NE. Waterman Cr.	O'Brien Co., Waterman Twp., Sec. 7, SE. Murry Cr.	O'Brien Co., Waterman Twp., Sec. 7, SE. Murry Cr.	O'Brien Co., Waterman Twp., Sec. 8, SW. Murry Cr.	O'Brien Co., Waterman Twp., Sec. 17, W. line. Murry Cr.	O'Brien Co., Waterman Twp., Sec. 34, NW. Big Sioux valley.	Cherokee Co., Spring Twp., Sec. 12, NW.	Buena Vista Co., Brooke Twp., Sec. 22, NW. corner.	Buena Vista Co., Brooke Twp., Sec. 14, S. line.	Cherokee Co., Spring Twp., Sec. 30, SW.	Cherokee Co., Cedar Twp., Sec. 25, SE.	Cherokee Co., Cherokee Twp., Sec. 13, NW. of NW. Doupe farm.	Cherokee Co., Cherokee Twp., Sec. 13, NW. Doupe farm.	Cherokee Co., Cherokee Twp., Sec. 11, SE. of NW.	Cherokee Co., Cherokee Twp., Sec. 11, NW. of SE. Knotts pit.	Cherokee Co., Cherokee Twp., Sec. 14, NW. of NE. Turner pit.	Cherokee Co., Cherokee Twp., Sec. 14, NW. of NE. Turner pit.	Cherokee Co., Cherokee Twp., Sec. 14, NW. of NE. Turner pit.	Cherokee Co., Cherokee Twp., Sec. 14, SW. of NE. Gilleas pit.	Average, Table V. 42 analyses.
Granite-syenite	16	16	18	10	15	18	9	21	20	15	23	17	25	18	17	22	18	22	14	25	23	18
Diorite-gabbro	--	--	1	1	2	--	2	--	--	2	2	--	1	2	3	--	2	--	--	--	2	1
Basalt	11	5	1	13	4	4	14	9	10	10	3	5	6	2	5	10	2	6	7	2	7	7
Quartz	1	--	--	--	1	2	1	--	--	--	4	--	1	--	1	--	--	1	--	--	2	1
Miscel. igneous	--	1	--	--	2	--	1	1	--	1	3	--	--	--	--	--	--	1	2	--	--	0
Total igneous	28	22	20	24	24	24	27	31	30	28	35	22	33	22	26	32	22	30	23	27	34	27
Quartzite	--	2	1	--	--	--	--	1	--	1	--	4	1	1	1	--	--	4	1	--	1	1
Chert and flint	--	--	1	--	--	--	1	--	1	1	3	--	--	3	1	--	2	2	--	2	--	1
Limestone and dolomite	72	76	77	75	76	76	72	64	69	69	61	72	65	66	72	68	72	61	76	68	65	70
Shale	--	--	1	--	--	--	--	3	--	--	--	2	1	8	--	--	3	2	--	3	--	1
Sandstone	--	--	--	--	--	--	--	--	--	--	1	--	--	--	--	--	1	1	--	--	--	0
Clay-balls	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Miscel. sedimentary	--	--	--	1	--	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	--	0
Total sedimentary	72	78	80	76	76	76	73	69	70	72	65	78	67	78	74	68	78	70	77	73	66	73

TABLE VI, SHEET 1

Analyses of Pebbles from Valley Gravels in Iowan Drainage Lines of the Kansan Region

	Lyon Co., Sioux Twp., Sec. 24, SW. Ry. pit.	Sioux Co., Buncombe Twp., Sec. 34, SE. Big Sioux Rv.	Sioux Co., Buncombe Twp., Sec. 34, SE. Big Sioux Rv.	Lyon Co., Riverside Twp., Sec. 33, SW. Rock Rv.	Lyon Co., Riverside Twp., Sec. 33, SE. Rock Rv.	Lyon Co., Riverside Twp., Sec. 33, SE. Rock Rv.	Lyon Co., Rock Twp., Sec. 27, SW. Rock Rv.	Lyon Co., Doon Twp., Sec. 26, Montgomery pit.	Lyon Co., Doon Twp., Sec. 26, E. line. Ry. pit.	Lyon Co., Doon Twp., Sec. 26, E. line. Ry. pit.	Sioux Co., Rock Twp., Sec. 17, SE. corner.	Sioux Co., Rock Twp., Sec. 21, S. line.	Sioux Co., Rock Twp., Sec. 19, SE. corner.	Sioux Co., Rock Twp., Sec. 19, NE., SE. corner.	Average, Table VI, Sheet 1. 14 analyses, Big Sioux and Rock Rv. valleys.
Granite-syenite	21	39	35	23	30	32	34	22	33	34	42	31	32	39	32
Diorite-gabbro	2	2	--	4	2	2	--	7	5	5	2	--	4	5	3
Basalt	8	19	13	15	13	6	3	8	6	4	12	18	13	4	10
Quartz	2	1	1	1	--	1	1	2	2	--	--	3	--	4	1
Miscel. igneous	--	3	--	1	--	2	--	4	2	1	1	1	--	1	1
Total igneous	33	64	49	44	45	43	38	43	48	44	57	53	49	53	47
Quartzite	7	2	3	5	2	3	4	8	2	8	1	4	6	7	5
Chert and flint	3	2	2	3	--	1	3	--	3	2	1	2	--	--	2
Limestone and dolomite	57	32	46	48	53	53	55	45	47	46	38	41	45	40	46
Shale	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Sandstone	--	--	--	--	--	--	--	2	--	--	1	--	--	--	0
Clay-balls	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Miscel. sedimentary	--	--	--	--	--	--	--	2	--	--	2	--	--	--	0
Total sedimentary	67	36	51	56	55	57	62	57	52	56	43	47	51	47	53

Their presence indicates that this gravel was not transported far by running water. These clay-balls are present in 19 of the 21 analyses of Table IV and average 12 per cent for the 21 analyses. One analysis shows 59 per cent of clay-balls. The presence of the clay-balls cuts down the percentages of other types of pebbles, so that granites, and igneous rocks as a whole, show lower percentages than in the other types (Table IX, column 4). Table V records the analyses from valley gravels of the Iowan region and Table VI the analyses from valley gravels in Iowan drainage lines of the Kansan region. These two types do not contain clay-balls. Tables IV, V and VI include all the gravels interpreted as Iowan in age. The average of the 96 analyses of these three tables is given in column 6a of Table IX. It is low in granite and total igneous and high in limestone, clay-balls and total sedimentary, but the differences are not such as can be used to differentiate Iowan gravels.

Table VII shows the analyses of valley gravels which are believed to have been derived from Kansan till, and Table VIII shows analyses of gravels inclosed in, or associated with Kansan till. The average

TABLE VI, SHEET 2

Analyses of Pebbles from Valley Gravels in Iowan Drainage Lines of the Kansan Region

	Lyon Co., Midland Twp., Sec. 15, SE. Tom Cr.	Sioux Co., Nassau Twp., Sec. 2, SE. corner. Floyd Rv.	Cherokee Co., Cherokee Twp., Sec. 33, NE. of SE.	Cherokee Co., Cherokee Twp., Sec. 34, SW. Ry. pit.	Cherokee Co., Cherokee Twp., Sec. 34, ¼ mi. E. of center.	Cherokee Co., Cherokee Twp., Sec. 34, ¼ mi. E. of center.	Cherokee Co., Pilot Twp., Sec. 9, SE. Little Sioux valley.	Cherokee Co., Pilot Twp., Sec. 22, NW.	Cherokee Co., Pilot Twp., Sec. 31, NE. of SE.	Cherokee Co., Willow Twp., Sec. 29, SE. of SW.	Cherokee Co., Willow Twp., Sec. 29, SE. of SW.	Woodbury Co., Union Twp., Sec. 33, NE. of NE. Fleming pit.	Woodbury Co., Union Twp., Sec. 33, NE. of NE. Fleming pit.	Woodbury Co., Kedron Twp., Sec. 15, W. Gilleas pit.	Woodbury Co., Kedron Twp., Sec. 15, W. Gilleas pit.	Woodbury Co., Kedron Twp., Sec. 33, NW. Anthon pit.	Woodbury Co., Kedron Twp., Sec. 33, SE.	Woodbury Co., Oto Twp., Sec. 5, N.	Ida Co., Galva Twp., Sec. 27, S. line. Maple Rv.	Average, Table VI, Sheet 2, 19 analyses, mostly from Little Sioux valley.	Average, Table VI complete. 33 analyses.
Granite-syenite	11	17	25	20	33	30	35	13	26	32	35	15	32	41	18	22	21	10	41	25	28
Diorite-gabbro	3	10	2	5	--	--	2	6	1	1	2	10	9	--	--	6	--	1	5	3	3
Basalt	7	17	6	6	4	7	6	13	2	26	21	13	12	16	17	19	36	19	6	14	12
Quartz	1	4	2	1	1	--	2	--	3	1	2	1	3	--	3	5	8	--	1	2	2
Miscel. igneous	--	--	1	--	3	--	4	4	--	1	2	1	3	5	--	3	--	4	2	2	1
Total igneous	22	48	36	32	41	37	49	36	32	61	62	40	59	62	38	55	65	34	55	46	46
Quartzite	1	2	1	3	--	2	1	6	1	5	6	12	9	5	5	7	4	2	8	4	4
Chert and flint	1	2	3	3	2	2	--	3	1	5	4	3	6	2	5	6	6	--	2	3	3
Limestone and dolomite	75	36	58	52	57	59	48	54	65	27	28	42	26	29	51	30	25	59	34	45	46
Shale	--	--	--	1	--	--	1	--	1	--	--	--	--	--	--	--	--	--	--	0	0
Sandstone	--	3	--	--	--	--	--	1	--	--	--	--	--	--	--	--	--	--	1	0	0
Clay-balls	--	--	--	--	--	--	--	--	--	--	--	--	--	2	1	1	--	--	--	0	0
Miscel. sedimentary	1	9	2	9	--	--	1	--	--	2	--	3	--	--	--	1	--	5	--	2	1
Total sedimentary	78	52	64	68	59	63	51	64	68	39	38	60	41	38	62	45	35	66	45	54	54

TABLE VII

Analyses of Pebbles from Valley Gravels of the Kansan Region in Drainage Lines Not Reached by Iowan or Wisconsin Drainage

	Lyon Co., Larchwood Twp., Sec. 24, NW. Mud Cr.	Lyon Co., Doon Twp., Sec. 15, S. line. Mud Cr.	Lyon Co., Doon Twp., Sec. 22, S. part. Mud Cr.	Plymouth Co., Marion Twp., Sec. 1, center. Deep Cr.	Plymouth Co., Marion Twp., Sec. 1, W. line. Deep Cr.	Plymouth Co., Marion Twp., Sec. 5, W. line. Deep Cr.	Plymouth Co., America Twp., Sec. 10, NW. Deep Cr.	Plymouth Co., America Twp., Sec. 9, NW. Deep Cr.	Plymouth Co., America Twp., Sec. 9, NW. Deep Cr.	Woodbury Co., Union Twp., Sec. 20, N. Pierson Cr.	Woodbury Co., Union Twp., Sec. 28, SE. Walsh pit.	Woodbury Co., Union Twp., Sec. 28, SE. Walsh pit.	Sac Co., Wheeler Twp., Sec. 26, W. line.	Average, Table VII. 13 analyses.
Granite-syenite	27	44	29	27	17	21	24	33	28	22	23	19	14	25
Diorite-gabbro	4	2	6	6	6	1	4	1	1	--	3	--	4	3
Basalt	19	7	9	9	17	20	18	14	16	10	21	18	16	15
Quartz	--	--	2	--	3	1	4	3	2	3	7	--	4	2
Miscel. igneous	5	--	--	1	--	4	2	--	3	1	5	2	6	2
Total igneous	55	53	46	43	43	47	52	51	50	36	59	39	44	47
Quartzite	7	11	7	11	6	--	5	3	4	9	10	5	9	7
Chert and flint	2	5	4	6	2	5	5	5	6	5	5	3	1	4
Limestone and dolomite	35	31	38	36	49	46	37	40	34	44	26	47	40	39
Shale	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Sandstone	--	--	--	3	--	2	1	1	1	--	--	3	2	1
Clay-balls	--	--	--	--	--	--	--	--	--	--	--	--	--	0
Miscel. sedimentary	1	--	5	1	--	--	--	--	5	6	--	3	4	2
Total sedimentary	45	47	54	57	57	53	48	49	50	64	41	61	56	53

for the 23 analyses of tables VII and VIII combined, being all the Kansan-derived material, is shown in column 8a of Table IX. It is high in basalt and total igneous and low in limestone and total sedimentary. In general, those gravels which are farther down the valleys to the south and southwest show a somewhat larger percentage of the more resistant rock types, such as basalt, quartzite, chert and flint. This is illustrated by comparing the analyses of columns 5, 6 and 7 of Table IX.

Table IX presents in summary form for ready comparison the averages of the several types of gravels in columns 1 to 8. Columns 3a, 6a and 8a give the averages for all the analyses of gravels interpreted as Wisconsin, Iowan and Kansan in age, respectively. Column 7a shows the average of the analyses in tables V, VI and VII combined, which include all the typical valley gravels of the Iowan and Kansan regions, a total of 88 analyses. Column 9 gives the average for all the analyses of all types recorded in the eight tables.

TABLE VIII

Analyses of Pebbles from Gravel Masses Enclosed in, or Associated with Till that Is Apparently Kansan

	Lyon Co., Sioux Twp., Sec. 36, SW. (R.49W.)	Lyon Co., Larchwood Twp., Sec. 11, NW.	O'Brien Co., Union Twp., Sec. 7, center.	O'Brien Co., Waterman Twp., Sec. 2, East bluff, Waterman Cr.	Clay Co., Peterson Twp., Sec. 33, N. N. of school.	Clay Co., Peterson Twp., Sec. 34, SW.	Cherokee Co., Pilot Twp., Sec. 11, N.	Cherokee Co., Pilot Twp., Sec. 28, NE.	Woodbury Co., Grant Twp., Sec. 25.	Woodbury Co., Little Sioux valley. S. of Correctionville.	Average, Table VIII. 10 analyses.
Granite-syenite	12	22	30	25	20	23	30	31	19	26	24
Diorite-gabbro	1	3	1	--	3	1	4	1	--	--	1
Basalt	5	9	5	5	5	3	15	12	12	14	9
Quartz	--	1	2	--	2	--	--	--	2	2	1
Miscel. igneous	1	--	18	--	--	--	3	6	--	6	3
Total igneous	19	35	56	30	30	27	52	50	33	48	38
Quartzite	12	6	9	--	--	3	1	4	3	2	4
Chert and flint	4	--	10	--	--	--	1	1	2	7	3
Limestone and dolomite	50	59	13	64	68	64	39	42	62	37	50
Shale	3	--	--	6	--	6	--	--	--	--	1
Sandstone	--	--	--	--	--	--	--	--	--	--	0
Clay-balls	12	--	--	--	--	--	--	--	--	--	1
Miscel. sedimentary	--	--	12	--	2	--	7	3	--	6	3
Total sedimentary	81	65	44	70	70	73	48	50	67	52	62

TABLE IX

Summary of Averages of Analyses of Pebbles from the Several Types of Gravel

	Till or gravel within Wisconsin Region. Table I, 15 analyses. (1)	Valley gravels of Wisconsin Region. Table II, 10 analyses. (2)	Wisconsin outwash beyond boundary. Table III, 18 analyses. (3)	Wisconsin gravels. Tables I, II, and III. 43 analyses. (3a)	Gravel hills of Iowan region. Table IV, 21 analyses. (4)	Valley gravels of Iowan region. Table V, 42 analyses. (5)	Iowan drainage lines in Kansan region. Table VI, 33 analyses. (6)	Iowan gravels. Tables IV, V, and VI. 96 analyses. (6a)	Valley gravels of Kansan region. Table VII, 13 analyses. (7)	Valley gravels, Iowan and Kansan Regions. Tables V, VI, and VII. 88 analyses. (7a)	Gravel masses from Kansan till. Table VIII, 10 analyses. (8)	Kansan gravels. Tables VII and VIII. 23 analyses. (8a)	Average for all analyses. All tables, 162 analyses. (9)
Granite-syenite	20	26	29	25	18	18	28	21	25	23	24	24	23
Diorite-gabbro	2	1	1	1	1	1	3	2	3	2	1	2	2
Basalt	9	7	7	8	4	7	12	8	15	10	9	12	8
Quartz	2	1	1	1	1	1	2	1	2	1	3	2	1
Miscel. igneous	2	1	2	2	--	--	1	1	2	1	1	3	2
Total igneous	35	36	40	37	24	27	46	33	47	37	38	43	36
Quartzite	3	3	3	3	2	1	4	2	7	3	4	5	3
Chert and flint	1	1	1	1	1	1	3	1	4	2	3	3	1
Limestone and dolomite	55	55	54	55	55	70	46	58	39	56	50	44	55
Shale	2	3	2	2	5	1	--	2	--	1	1	1	2
Sandstone	--	1	--	0	--	--	--	0	1	--	--	1	0
Clay-balls	2	--	--	1	12	--	--	3	--	--	1	1	2
Miscel. sedimentary	2	1	--	1	1	--	1	1	2	1	3	2	1
Total sedimentary	65	64	60	63	76	73	54	67	53	63	62	57	64

CHAPTER VII

GEOLOGIC HISTORY AND CONCLUSIONS

Pleistocene History

The geologic history of northwestern Iowa was traced in the report of 1917[54] but the changes of interpretation used in the present report require that a part of the Pleistocene history be restated. The bases for the interpretations, and most of the interpretations have been stated in earlier parts of this report but are repeated here as a part of a connected tracing of the history.

Nebraskan Age.—The first ice sheet which invaded northwestern Iowa was the Nebraskan, the oldest ice sheet recognized in the Mississippi basin. It covered all of western Iowa, pushing southward into Missouri, and on its withdrawal left a mantle of 200 to 300 feet of till over much of northwestern Iowa. The Nebraskan ice advanced over a region underlain largely by soft Cretaceous shale and it left a compact, calcareous till with very little sand or gravel.

During the Aftonian interglacial age which followed there was developed over the level Nebraskan till plain in southern Iowa a horizon of gumbotil formed chiefly by long-continued chemical weathering. In northwestern Iowa the evidence is not so clear and decisive, but it is sufficient to show that a similar gumbotil zone developed as far north as Cherokee county and it probably extended over all of northwestern Iowa. This gumbotil plain was then dissected, probably quite completely so, before the close of the Aftonian interglacial age. In the Cherokee region the erosion surface had a relief of 50 to 75 feet (page 76).

Kansan Age.—Following the Aftonian interglacial age the Kansan ice sheet developed. It advanced southward across Minnesota and Iowa, eastern North and South Dakota and eastern Nebraska and covered northern Missouri and northeastern Kansas. Its thickness in northwestern Iowa was probably several thousand feet. As the Kansan ice sheet advanced over the eroded surface of Nebraskan till it plowed up great quantities of the Nebraskan, which it mixed with the

54 Iowa Geol. Survey, Vol. XXVI, pp. 430-443, 1917.

material already carried, to make part of the Kansan till. Some small masses were inclosed without mixing in the Kansan till and at places the Kansan ice plowed up the Nebraskan surface but only partly mixed the tills, thus forming a transition zone. The thickness of Kansan till deposited was in most places between 100 and 200 feet.

For the history of the time following the withdrawal of the Kansan ice sheet we are again dependent upon the region farther south in Iowa. Over southern Iowa, as far north as Crawford and Carroll counties, the even drift plain left by the Kansan ice sheet remained for a long time undissected and on this plain there was developed a gumbotil zone. It is believed that a similar gumbotil zone was developed also over northwestern Iowa (pages 108 to 111). The development of these Nebraskan and Kansan gumbotils must have taken place very slowly and the Aftonian and Yarmouth intervals must have been very long.

Following the development of the Kansan gumbotil, the Kansan drift region was elevated and erosion began. In southern Iowa this erosion has lowered most of the country below the gumbotil plain but has left a few remnants. In northwestern Iowa there are no remnants of the gumbotil, and erosion is believed to have reduced all the country below the level of the original plain and to have removed every remnant of the gumbotil and of the leached zone of Kansan till below (pages 108 to 111).

The interval of time from the Kansan to the next ice invasion of northwestern Iowa (Iowan) includes the Yarmouth and Sangamon interglacial and the Illinoian glacial ages. The Kansan gumbotil was formed during the Yarmouth age. The dissection of the region continued through the Illinoian and Sangamon ages. During the later part of this interval silts and fine sands accumulated in some of the valleys of western Iowa, forming what are known as the Loveland deposits.

Iowan Age.—After the erosion of the Kansan region had progressed nearly to its present condition, northern Iowa was invaded by another ice sheet, the Iowan, which pushed into our region from the northeast to a line extending from eastern Lyon county through Cherokee to southwestern Sac county (Plate I). The Iowan ice sheet appears to have deposited only a thin veneer of drift in most places. It did not, therefore, make a distinctive constructional topography, but merely mantled the then existing topography cut in the Kansan drift, producing a region in which the larger relief features are erosional but with the slopes modified by minor constructional features (page 41).

During the general stage of ice advance there were temporary withdrawals, and during the general stage of retreat there were temporary advances. As a result of these oscillations of the ice front, gravel that was laid down just beyond the ice front was later overridden and buried under till. In some places the oscillations were repeated several times and resulted in several alternations of the till and gravel as described for the Mill creek bluffs north of Cherokee (pages 84 to 88). Deposits in moulins in the ice or at the edge of the ice formed the kamelike gravel hills (pages 90 to 102).

During the advance, and particularly during the withdrawal of the Iowan ice sheet, great floods of water loaded with debris flowed out from its front, down the valleys to the south and southwest and deposited gravel in most of the valleys of the region, forming the deposits which have been described in Chapter V as the valley gravels.

After the Iowan ice age, and apparently soon after the deposition of the valley gravels, northwestern Iowa was covered with a mantle of loess, the material for which was derived chiefly from the valley flats on the west line of the state. Near Missouri river 20 to 30 feet of loess were deposited, but this decreased eastward across the Kansan region to two to four feet over most of the Iowan region. Since the loess was formed it has been leached to a depth of two to four feet, but on the whole the Iowan drift region has suffered little erosion and the till is notably fresh.

Wisconsin Age.—At a still later date a lobe of the Wisconsin ice sheet advanced southward across north-central Iowa, with its west edge across the eastern part of our region, as shown on Plate I. The Wisconsin ice sheet left a drift surface with definite glacial features, including prominent morainic topography. Very little modification of this topography has been produced by the erosion of post-Wisconsin time except along some of the larger streams, which have cut prominent trenchlike valleys.

Summary of Conclusions

Conclusions and interpretations have been given in connection with each subject discussed but brief statements of the more important conclusions are brought together here in the form of a summary.

Iowan Region.—Two drift regions exist in northwestern Iowa west of the Wisconsin drift boundary in the area previously interpreted as Kansan (Plate II). The eastern part of this area, lying between the definite Wisconsin on the east and the more definite Kansan on the west, is here differentiated as a distinct drift region formed by an ice sheet that pushed into northwestern Iowa from the northeast and advanced about halfway across our region to a boundary shown on Plate I and traced on pages 59 to 84. The peculiar topography of this region, consisting of a well developed valley system with faintly constructional slopes, is explained by the interpretation that the ice sheet which formed this region deposited only a thin mantle of drift which modifies slightly a pre-existing erosional topography (page 41).

This drift region is assigned to the Iowan age and correlated with the Iowan of eastern Iowa on the bases of similar topography, similar relations to the Kansan below and to the overlying mantle of loess, and similar geographical positions with respect to the later Wisconsin drift region (page 39).

Kansan Region.—That part of northwestern Iowa west of the Iowan boundary is interpreted as Kansan. The absence of leached till in this Kansan region as contrasted with the Kansan region farther south in western Iowa is explained by the interpretation that northwestern Iowa suffered more extensive erosion which completely removed the leached zone and gumbotil zone, if these had been developed (pages 108 to 111). This erosion took place before the Iowan age. The possibility of explaining the absence of the leached zone by assuming that it was never developed, owing to some climatic differences, is recognized.

The Loess.—Both the Kansan region and the Iowan region are covered with loess (pages 116 to 136). In the southwest part of our area, near Missouri river, this is typical loess and is thick. To the northeast it becomes thinner and over much of the Iowan region it is only two to four feet thick. Lithologically this thin loess may not be typical loess, but it is certainly the time equivalent of the loess. The age of this loess is interpreted as Peorian, as in eastern Iowa (pages 134 to 136).

Interbedded Gravel and Till.—An interbedding of gravel and till characterizes several exposures within the Iowan region (pages 84 to 89). These deposits were formed by oscillations of the ice front during the general stages of advance and retreat. By these oscillations, gravel deposited just beyond the ice edge may have been laid down on till only recently deposited and may soon have been buried by till. The freshness of the gravel and till of these layers shows that neither was exposed long at the surface before the next higher member was deposited.

The Gravel Hills.—The kamelike gravel hills of the Iowan region (pages 90 to 102) 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.

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 (pages 166 to 170). 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 (pages 168 to 170).

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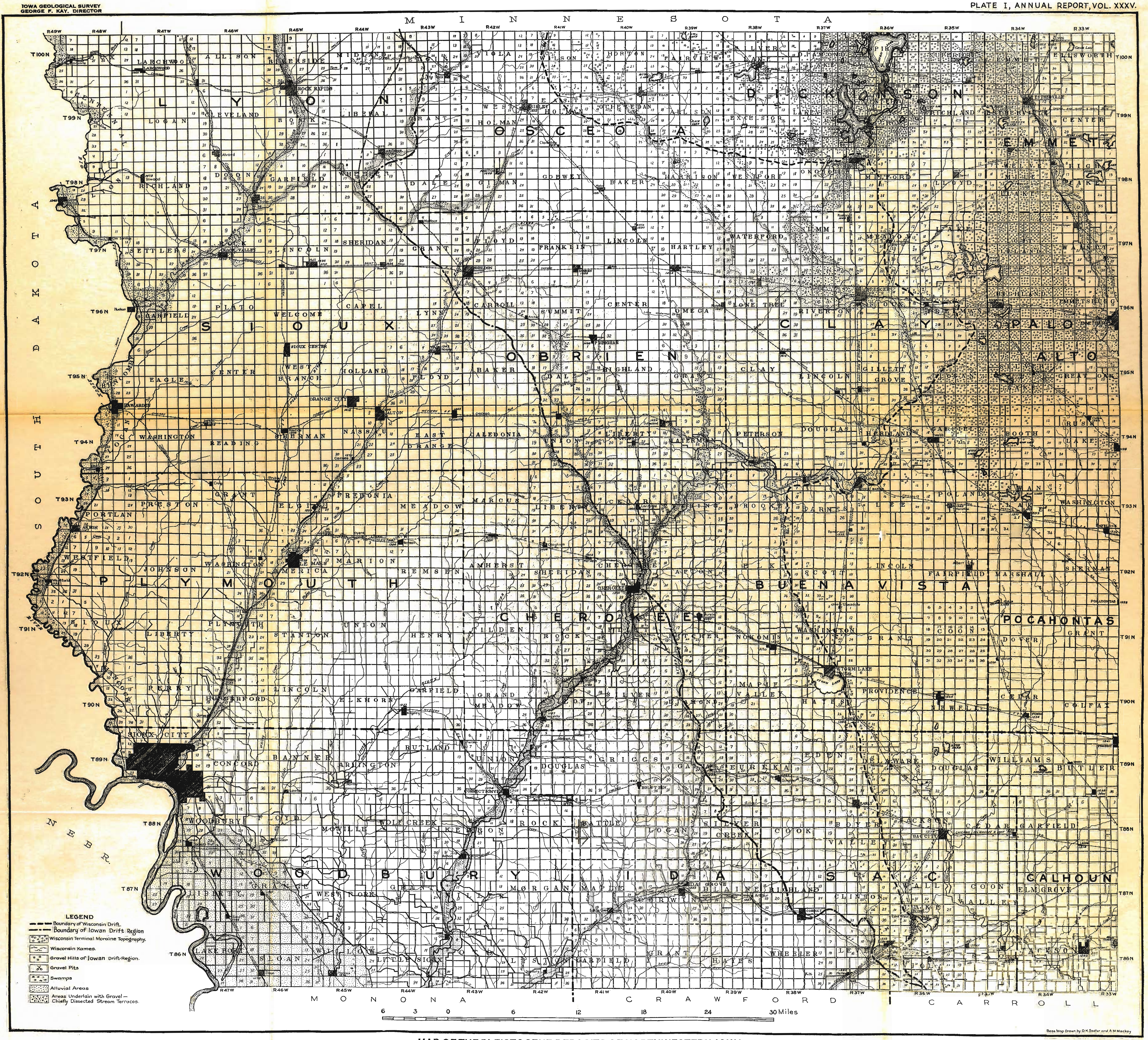

Base Map Drawn by O. H. Sadler and A. M. Mackay

MAP OF THE PLEISTOCENE DEPOSITS OF NORTHWESTERN IOWA

BY J. ERNEST CARMAN, 1929

THE DAKOTA STAGE OF THE TYPE LOCALITY

by

ALLEN C. TESTER

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PREFACE

The data and conclusions presented in this paper represent a small amount of the material which the writer has accumulated on the subject of the Dakota rocks. The first field work was done in 1924 as a general study of the Dakota stage in Kansas under the auspices of the Kansas Geological Survey. In 1926 arrangements were made with the Iowa Geological Survey to make field investigations of the Dakota rocks in northwestern Iowa and adjacent parts of Nebraska and South Dakota. During subsequent years some additional studies were made in Kansas, Nebraska and Iowa.

In Chapter VI numerous references are made to the Dakota rocks of Kansas with the hope that such information will be valuable in understanding the interpretations made of the Dakota rocks of the type locality. The writer wishes to make acknowledgment at this time to the Kansas Geological Survey for the use of such material. A complete report on the Dakota rocks of Kansas is now being prepared and will be published by the Kansas Geological Survey. Additional studies were made during the 1930 and 1931 field seasons for this report and the mapping of the formations of the Dakota will be completed in 1932.

It was a fortunate arrangement that permitted the writer to study the Dakota rocks from southern Kansas, across Nebraska, and in northwestern Iowa, independent of state boundaries. The problem is one which is distinctly of a regional nature and the student should not be handicapped by artificial boundary restrictions.

CHAPTER I

INTRODUCTION

Interest in the Dakota sandstone and its associated clay and silt members is almost as old as the study of stratigraphy in the United States. Because of the excellent exposures of the basal Cretaceous rocks along one of the main routes of early travel and exploration it is not unusual that we find records of observations made along the upper Missouri river in the early part of the nineteenth century. The very fact that at least four principal divisions of the Cretaceous of North America have their type localities in the upper Missouri river country is significant of the work accomplished by the early explorations.

The writer has spent a part of five field seasons at intervals during the last eight years studying the various phases of the formations discussed in this paper. The work has not been confined to Iowa but has also included a critical study of the beds in Nebraska, Kansas and South Dakota and finally some observations in Colorado and New Mexico. The first work was done in Kansas, where the Dakota had been separated from the marine Belvidere formation of Washita age. Because of certain close relationships between the Belvidere formation and beds usually classified with the Dakota, it seemed logical that a careful study should be made of the type exposures of the Dakota along Missouri river. The data and conclusions presented in this paper are the results primarily of observations made in northwestern Iowa, northeastern Nebraska, and eastern South Dakota. With the exception of a few general stratigraphic studies in conjunction with quadrangle or county mapping the work of Gould in 1900 was the last regional study made of the Dakota in the area under consideration. It is not unusual then that some new facts would be obtained and new interpretations made with the more modern background available in the field of geology.

Of the recent investigations on the lower Cretaceous formations in the Middle west, the work of Twenhofel[1] has been especially helpful.

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[1] Twenhofel, W. H., Geology and Invertebrate Paleontology of the Comanchean and "Dakota" Formations of Kansas: State Geol. Survey of Kansas, Bull. 9, 1924, 135 pp., ills.

He made a careful restudy of a complex section and on the basis of fossil identifications showed that certain horizons commonly described as Dakota should be correlated with the Washita formation of Oklahoma and Texas.

In the type locality of the Dakota sandstone, which for all practical purposes includes the exposures in Iowa at Sioux City, the marine fossils belong to the fauna which occurs in Kansas. For this and other reasons it will be shown that the Dakota sandstone represents formations that include a part of the Comanchean and Cretaceous systems of some writers, and that no such division into systems can be justified.

CHAPTER II

THE TYPE SECTION OF THE DAKOTA STAGE

Meek and Hayden were the first to make geologic sections of the rocks exposed along the upper Missouri river. As a part of their description they made divisions which ultimately became the type divisions of the upper Cretaceous of the central interior of the United States. The term "Dakota Group" was first applied in 1861[2] to that part of the section which had previously been called "Formation No. 1".[3] As a part of their system of using geographic names for rock formations, Meek and Hayden gave as the type locality of the "Dakota group" the "Hills back of the town of Dakota; also extensively developed in the surrounding country in Dakota county (Nebraska) below the mouth of Big Sioux River."[4]

The final description of the Cretaceous rocks of the Upper Missouri country was given in a paper presented to the Philadelphia Academy of Natural Sciences in 1861[5] and was repeated in the comprehensive report of Meek in 1876.[6] The only changes from the earlier publication were of punctuation, the correction of one generic name, and the addition of one new species. For the sake of accuracy the later[7] description is given below:

"Yellowish, reddish, and occasionally white sandstone, with, at places, alternations of various colored clays and beds and seams of impure lignite; also silicified wood, and great numbers of leaves of the higher types of dicotyledonous trees, with casts of *Pharella(?) dakotensis, Trigonarca siouxensis, Cyrena arenarea, Margaritana nebrascensis, etc.*"

The localities of exposure and study:

"Hills back of the town of Dakota; also extensively developed in the surrounding country in Dakota county below the mouth of Big Sioux River and thence extending southward into northeastern Kansas and beyond."

In many respects it is unfortunate that this series of rocks, which

2 Meek and Hayden, Phila. Acad. Nat. Sci. Proc., 1861, Vol. 13, p. 419, 1862. See also Meek, F.B., U.S.G.S. Terr., Vol. 9, p. 25, 1876.
3 Meek and Hayden, Phila. Acad. Nat. Sci. Proc., Vol. 8, pp. 63-69, 1856; Vol. 9, pp. 117-148, 1857. See also Hayden, F.V., Phila. Acad. Nat. Sci. Proc., pp. 109-116, 1857.
4 Op. cit., Phila. Acad. Nat. Sci. Proc., Vol. 13, p. 419, 1861.
5 Meek and Hayden, Phila. Acad. Nat. Sci. Proc. 1861, p. 419, 1862.
6 Meek, F. B., U. S. G. S. Terr., Vol. 9, p. 25, 1876.
7 Meek, F. B., Idem. p. 25.

has been so widely described and correlated, should have been given the name Dakota. It is true that the rocks are exposed in Dakota county, Nebraska, and that sandstones are exposed some six miles west and southwest of Dakota City, the county seat, but much better exposures and more complete sections are found on the Iowa side of the Missouri and along the bluffs facing Big Sioux river. A much more appropriate name would have been "Sioux" group or stage, because of the excellent exposures along Big Sioux river and adjacent to the then growing village of Sioux City, and also because the area was at the gateway to the Sioux Indian nation lands. The term is now used to designate the Sioux quartzite of pre-Cambrian age but was available at the time the Dakota was named.

CHAPTER III

REVIEW OF PREVIOUS WORK

The literature on the Dakota stage is very extensive. The name, as commonly used, has been applied to a sandstone and shale formation lying at the base of the marine Benton formation throughout the central interior of the United States and on both sides of the Rocky Mountains. The scope of the present paper does not consider these wide correlations, hence it is impractical to discuss the Dakota beyond the type area. All of the available literature dealing with the lowest of the Cretaceous rocks in northeastern Nebraska and adjacent Iowa has been studied, and these references comprise Part I of the bibliography.

The reprints of the original journals of the Lewis and Clark expedition up Missouri river in 1804-1806[8] are disappointing in their content of notes on the geology of the region traversed. It is probably true that the short delay caused by the death of Sergeant Floyd just below the present site of Sioux City caused Lewis and Clark, and other members of the party who kept journals, to record the topography of the region and the general character of the rocks and to do some collecting of rock and mineral specimens.

Captain Clark in his original account[9] describes a rock formation at a locality north of the present village of Decatur, Burt county, Nebraska. This is probably the earliest printed account which calls attention to the Dakota rocks adjacent to the type area. He relates noticing a "yellow, soft sandstone" in the bluffs on the west side of Missouri river near the place of the Mahar (Omaha) Indian Chief Blackbird burial mound. Again, in the diary for the following day (August 12, 1804), he tells of seeing the soft sandstone in the west bluff and observes that many springs issue from the sandrock. The last locality is probably about four or five miles southeast of Homer, Dakota county, Nebraska.

An interesting note is given in Clark's journal for August 22, 1804,[10]

[8] Thwaites, Reuben Gold, Original Journals of Lewis and Clark, 1804-1806. New York, 1904. 7 vols.
[9] Idem, Vol. 1, p. 106.
[10] Op. cit., p. 116.

following the death and burial of Sergeant Floyd. He tells about seeing in the rocks "copperas, cobalt, pyrites; an alum rock, soft and sandstone. Capt. Lewis determined the cobalt, which had the appearance of soft Isonglass." The best determination which the writer can make places this locality 15 to 18 miles above Sioux City, possibly near the mouth of Aowa creek, and the formations may be either the upper part of the Dakota or the base of the Graneros. Seven miles farther upstream Clark describes "a Clift of allom stone of a Dark Brown colr. containing also incrusted in the crevices and shelves of the rock great qts. *(quantities)* of Cobalt, Semented Shels & a red earth".[11] (The spelling and capitalization are the same as in the original journal.) This is probably the steep bank north of Ponca, Nebraska.

The various scientific observations made by Lewis and Clark are contained in volume 7 of the Thwaites edition. The notes on Mineralogy were edited by Prof E. H. Barbour of the University of Nebraska. The party collected some shells and various rock and mineral specimens and on their return deposited them with the American Philosophical Society.[12] The shells were not described and the crude determinations by Lewis of the minerals made the collections of little value.

Meek[13] states that Nuttall and Long brought back Cretaceous fossils from their expeditions into the upper Missouri country in 1809 and 1819 respectively. These shells were not studied and identified until several years after the return of the explorers, and they did not aid in the recognition of the age of the rocks while in the field.

The journeys of Bradbury and Nuttall in 1809-1810 into the upper Missouri river country contributed little of value concerning the rocks of the Sioux City area. Bradbury was not interested in geology, and Nuttall was a better botanist than geologist. In Bradbury's book published in London in 1817,[14] there is a description of the reddish bands in the rocks which he called hematite. As this feature was noted near the Yankton Indian villages and below Niobrara river, it is possible that the rocks observed belong to the Dakota stage.

The first published work of Nuttall concerning his trip into the upper Missouri country appeared in 1821[15] and shows an effort to correlate the formations exposed along the river with other rocks which Nuttall had observed in Arkansas territory and elsewhere. He says: "While

11 Idem, p. 117.
12 Idem, Vol. 7.
13 Meek, F. B., U.S.G.S. Terr., Vol. 9, p. 21, 1876.
14 Bradbury, John, Travels in Interior of America in 1809-1811.
15 Nuttall, T., Phila. Acad. Nat. Sci. Jour., Vol. 2, pp. 14-52, 1821.

ascending the Missouri in the summer of 1810, I could not ascertain the existence of the compact calcareous rock, containing organic reliquiæ, beyond the confluence of the river Platte; yet the sandstone hills and woodless plains in the rear of the Maha village, were precisely such as we met with along the northern borders of the Arkansas within the limits of Pottœ, and the Saline rivers."[16] In this instance he was probably referring to the Dakota sandstones of central Kansas. If this is the case, it is the first correlation of the sandstone series of northeastern Nebraska with those of central Kansas.

Farther up the river Nuttall collected a fossil Ostrea and an unknown species of Baculites from the bluish gray clay "abounding in pyrites and xylanthrax." In describing the calcareous cliffs not far from the creek of the Maha village, he says they "more closely resembled chalk than anything of the kind which I have heretofore seen or heard of in North America, but cannot by any means be identified with the same formation in the south of England and in France. We could not discover in it any organic reliquiæ, nor any vestiges of flint."[17] In spite of this statement recent writers have given Nuttall credit for being the first to recognize the chalk of North America as being correlative with similar beds in England and also claim he recognized the beds along Missouri river because of their fossil content.

Keyes in Vol. XXII, Iowa Geological Survey, 1913, page 50, says: "Another important geologic correlation is to be credited to Nuttall. On his journey up the Missouri river in 1810, which he undertook with John Bradbury, a Scotch naturalist, he reached the Mandan villages on the upper reaches of that stream. He makes especial mention of the Omaha villages situated below the mouth of the Big Sioux river. A short distance upstream from the last mentioned point he examined strata which by means of their fossils presumably, he referred to the Chalk division of the Floetz or Secondary rocks of northern France and southern England. This is the earliest definite recognition of beds of Cretaceous age in America." It seems true that Nuttall used the principle of William Smith in the correlation of formations by their fossil content in the case of the Mississippian rocks (p. 14 of Nuttall) but he failed to find the fossils which would permit him to do the same for the Cretaceous rocks of the upper Missouri country. The word 'Maha' used by Nuttall and others was the common usage for the present word Omaha, as used by Keyes.

Thomas Say, in the report of Edwin James on the Long expedition

16 Idem, p. 24.
17 Nuttall, op. cit., p. 25.

to the Pacific,[18] identified and described shells obtained by Thomas Nuttall in 1819 from "along the Kiamesha river in Arkansas." These are named *Gryphaea corrugata* and *Ostrea*. No mention is made of the strata being correlative with European beds.

Vanuxem was the first geologist in America to recognize the existence of strata in this country which could be correlated with the Cretaceous formations of England. Morton presented Vanuxem's notes to the Philadelphia Academy in 1828,[19] showing the latter's recognition of the age of the strata in New Jersey on the basis of the fossils. "The pelagian fossils by which this formation is characterized, affords ample evidence that it belongs to the Secondary and not, as commonly supposed, to the Tertiary class."[20] The following year Vanuxem[21] pointed out certain errors in Maclure's classification of the beds of the Atlantic coastal plain and showed that the 'alluvial' of Maclure contains littoral shells similar to those of the English and Paris basins and pelagic shells like those of the chalk deposits of England. With the correlation of Cretaceous rocks made along the Atlantic coast, it was not long until it was recognized that many of the fossils brought from the upper Missouri country, Arkansas and New Mexico came from beds of nearly the same age. Morton continued to contribute[22] to the knowledge and classification of the "ferruginous sandstone formation"[23] of New Jersey and after comparing the fossils with those from the Green Sand of England was struck by the resemblance. His classification of the beds below the Tertiary is essentially the same as that used today. Finally, in 1833, Morton[24] summarized the great progress which was then being made in the extension of the classification of the marl beds to include the formations of almost all the south Atlantic and Gulf states and extending into the Arkansas river country and upper Missouri country. He stated that Lewis and Clark, Nuttall, Col. Long and others "found *Baculites, Hamites (?), Gryphaea* and other marl fossils at the Great Bend of

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18 James, E., "Account of Expedition from Pittsburg to the Rocky Mountains performed in 1819-1820. Description of fossils by Thomas Say, Vol. 1, p. 106, and Vol. 2, pp. 410-411. Phila., 1823.

19 Morton, S. G., Phila. Acad. Nat. Sci. Jour., Vol. 6, 1828, pp. 59-71, 1829.

20 Idem, p. 62.

21 Vanuxem, L., Am. Jour. Sci., Ser. 1, Vol. 16, p. 254, 1829.

22 Morton, S. G., Am. Jour. Sci., Ser. 1, Vol. 17, pp. 274-295, 1830. See also Am. Jour. Sci., Vol. 18, pp. 243-250, 1830.

23 At that time Conybeare and Phillips divided the ferruginous sandstone group of England into four divisions: (from top down) 4. Chalk marle, 3. Green Sand, 2. Weald Clay, 1. Iron Sand.

24 Morton, S. G., Am. Jour. Sci., Vol. 23, pp. 288-294, 1833.

the Missouri river - - - intimating the existence of the ferruginous sand in that remote region of our continent."[25]

Nicollet was the next geologist to report on the Cretaceous of the upper Missouri river country. He gives a section[26] which he examined near the mouth of 'Ayoway' (Aowa) river. At the base of this section he found three feet of argillaceous limestone containing *Inoceramus* and disseminated iron pyrite, overlain by 30 feet of calcareous marl containing fish scales and a few other fossils. These rocks, he says, always constitute the base of the Cretaceous of the upper Missouri country and rest immediately on the Carboniferous limestone. Apparently Nicollet missed the Dakota sandstone entirely.

Sir Charles Lyell[27] obtained some information concerning the Cretaceous rocks of the Missouri country from G. W. Featherstonhaugh and Prince Maximilian von Wied. However, Lyell's geologic map of the United States shows the base of the Cretaceous occurring higher on Missouri river than the type area of the Dakota sandstone.

Owen[28] mentions the Cretaceous of the Sioux City area in recording a part of Evans' report to him. Evans saw the Cretaceous rocks near the mouth of Aowa creek and by using the lithological characters described by Nicollet was able to trace the beds beyond Fort Pierre. No detail is given concerning the Dakota, but several fossils are recorded in the younger beds.

Jules Marcou contributed many observations on the rocks of the western part of the United States and particularly of the Rocky mountain region. He published in 1855[29] a long article explaining his geologic map of the United States. This was the first paper of any length which attempted a systematic explanation of the formations of the United States and, even with its many mistakes, was a distinct advance in the study of geology. In fact, the furor incited by Marcou's interpretations gave a great impetus to further investigations. His mapping of Triassic, Jurassic and Cretaceous formations especially was challenged, and much disagreement arose concerning his correlations. He made no observations on the upper Missouri river at this time so could contribute nothing new on the Cretaceous section of that locality.

25 Idem, p. 292.
26 Nicollet, J. N., Am. Jour. Sci., Ser. 1, Vol. 41, pp. 180-182, 1841.
27 Lyell, Charles, Travels in North America, London, 1845.
28 Owen, D. D., Geological Survey of Wisconsin, Iowa and Minnesota, and incidentally a portion of Nebraska Territory; made under direction of U. S. Treasury Dept., p. 195, Phila., 1852.
29 Marcou, J., Bull. Geol. Soc. France, Ser. 2, Vol. 12, pp. 813, 936.

The first good study of the stratigraphic sequence of the Cretaceous beds of the upper Missouri country was published in 1856 by James Hall and F. B. Meek.[30] The expedition which made this study was composed of Meek and Hayden, but the fossils collected were studied by Hall, who also made the figures for illustration. While descending Missouri river from Fort Pierre to near Omaha, particular attention was given to the lithological characters, the order of succession, and characteristic fossils of the various divisions of the Cretaceous. As a result of their studies the first stratigraphic section was obtained. For comparison it is given below.[31]

"*Cretaceous Formation*		FEET
5.	Arenaceous clays passing into argillo-calcareous sandstones ...	80
4.	Plastic clays with calcareous concretions, containing numerous fossils .... (This is the principal fossiliferous bed of the Cretaceous formation of the upper Missouri.)	250
3.	Calcareous marl containing *Ostrea congesta*, scales of fishes, etc.	100 to 150
2.	Clay containing a few fossils	80
1.	Sandstone and clay .... Underlain by buff-colored magnesian limestone of Carboniferous period."	90

The thickness of the various beds is only approximate, having been derived from a study of the exposures seen in several localities. The reference cited contains many fine illustrations of fossils described and figured for the first time.

In 1856 Meek and Hayden[32] published their first joint article to include a stratigraphic section of the upper Missouri river Cretaceous. The five divisions are as follows:

"*Cretaceous System*		FEET
5.	Gray and yellowish arenaceous clays containing great numbers of marine mollusca with a few land plants	100 to 150
4.	Plastic clays with numerous marine mollusca	About 350
3.	Gray and yellowish calcareous marl, containing *Ostrea congesta*, fish scales, etc.	100 to 150
2.	Grayish and lead-colored clays, having few fossils	80
1.	Sandstones and clays not positively known to belong to the Cretaceous system	90"

Limestones of the upper Coal Measures as observed near Council Bluffs, Iowa, underlie the section noted above. A description of 28 species of gastropods follows, but none of the forms comes from the lower three divisions.

The Dakota, as defined later by the same writers, is number one of

30 Hall and Meek, Am. Acad. Arts and Sci. Mem., Boston, N. S., Vol. 5, pp. 379-411, 1856.
31 Idem, p. 505.
32 Meek and Hayden, Phila. Acad. Nat. Sci. Proc., Vol. 8, pp. 63-69, 1856.

the section. During the early studies of division number one Meek and Hayden were not certain concerning its proper age.

In a paper presented to the Philadelphia Academy in November, 1856, Meek and Hayden[83] developed more fully the Cretaceous section of Nebraska Territory and gave a complete catalogue of the invertebrate remains described and identified up to that time from the Cretaceous and Tertiary formations of that region. The fossil lists include over 140 species from the five divisions. For formation No. 1 of the section (the Dakota) 17 species are listed, but 13 species are questionably referred to this formation. At this time certain exposures near the mouth of Judith river were correlated with formation No. 1, and most of the 17 species came from that locality. No invertebrates had been collected, at that time, from formation No. 1 at the mouth of Big Sioux river or the type area of the Dakota stage.

The principle of correlation by the use of fossils, and also of the differences of species in widely separated localities was well understood at this time, as is indicated by the comparisons made by Meek and Hayden. They say concerning the 147 Cretaceous species listed in their catalogue, "nine appear to be common to the Nebraska formations and those of the states, and four are identical with forms occurring in the old world."[84]

Subdivision No. 1 of the Cretaceous system as given in this paper is quoted below:

> "Heavy bedded yellowish sandstone, passing downwards into alternations of sandstone and clay, containing bits of water-worn lignite and bands of dark carbonaceous matter. This formation is not positively known to belong to the Cretaceous System."[85]

The thickness of this formation near the mouth of Big Sioux river is given as between 90 and 100 feet.

The next year Hayden elaborated still further on the Missouri river section. This description contains the names of three genera of mollusks collected from the locality near the mouth of the Big Sioux river. Dr. Hayden's section is as follows:[86]

"In order of superposition, Formation No. 1 rests directly upon the true limestones of the Coal Measures before referred to. Its first exposure seen along the Missouri is at Wood's Bluffs, right bank, about

83 Meek and Hayden, Phila. Acad. Nat. Sci. Proc., Vol. 8, pp. 265-286, 1856.
84 Op. cit., p. 266.
85 Idem, p. 269.
86 Hayden, Phila. Acad. Nat. Sci. Proc., Vol. 9, p. 111, 1857.

eighty miles above the mouth of the Platte, and it dips beneath the water level of the Missouri, a few miles below the mouth of the Vermilion. Its general character is a coarse grained, friable sandstone, very ferruginous, of a yellow or reddish yellow color, with thin beds of impure lignite and various colored clay. It contains very few fossils, mostly of the genera *Solen, Cyprina* and *Pectunculus,* also fossil wood, and numerous impressions of dicotyledonous leaves, similar to the common willow. Its entire thickness is estimated at ninety to one hundred feet, but it may be more."

As indicated on the previous pages, Meek and Hayden entertained some doubts as to the proper age of formation No. 1 and placed it provisionally in their published sections as a part of the Cretaceous system. After a careful review of the subject and more extended field work they were able to state in 1858,[37] with perfect satisfaction, that the formation could not be older than the Cretaceous. Their evidence for this was found partly in the modern affinities of the numerous dicotyledonous leaves which they found at numerous localities and partly in the stratigraphic relationships with the overlying formation number two.

At the time Meek and Hayden were accumulating their data for the determination of the age of formation No. 1, they traced the rock southward from Nebraska into Kansas to a point near Smoky Hill river. At this locality there are no rocks overlying the sandstones of formation No. 1, so they had no stratigraphic evidence relating it to formation No. 2 but were well satisfied with their correlation, as they state: "Our lithological and paleontological evidence is quite conclusive - - - for this rock in color, composition, and all other respects, is undistinguishable from number one of the Nebraska section, as seen near the mouth of the Big Sioux river on the Missouri, and contains numerous fossil leaves, some of which are identical with those appearing in number one at the last mentioned locality."[38]

Dr. Newberry passed judgment on the age of the leaves mentioned in the above paragraph and was of the opinion that they are certainly Cretaceous, some of them belonging to genera peculiar to that time, and that the whole flora is of a more highly organized group of plants than anything known in the Triassic or Jurassic flora. As will be indicated on a later page of this paper, Meek and Hayden had been informed by Professor Heer[39] that the leaves from formation No. 1 belonged to a Miocene flora.

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[37] Meek and Hayden, Phila. Acad. Nat. Sci. Proc., Vol. 10, p. 256, 1858.
[38] Idem, p. 258.
[39] Heer, O., Phila. Acad. Nat. Sci. Proc., Vol. 10, pp. 265-266, 1858.

In 1857 Hall[40] published his report on the geology and paleontology of the Mexican boundary and general observations on the Cretaceous strata of the United States. Hall reviews the general knowledge of the Cretaceous rocks of New Jersey, the south Atlantic and Gulf States and Nebraska. He refers to the collections of fossils made by the various explorers and geologists from the time of the Lewis and Clark expedition. He suggests that formation No. 1 of the Nebraska section is probably the equivalent of Nos. 1 and 2 of the New Jersey section, and also that it might be the equivalent of the various sandstones, shales and clays at the base of the formations in Llano Estacado. The main part of the paper deals with correlations of formations 2 and 3 of the upper Missouri river section, but for all the rocks Hall suggests the possibility of considerable variation in the thickness and lithologic character when traced over a wide area. He thought it very likely that some of the strata of the southwest were not represented in Nebraska and that others that were represented might be of different character.

For a period of several years a great controversy raged between Meek and Hayden and Newberry and their followers, and Marcou, Heer and other European geologists concerning the age of the various Cretaceous formations in Nebraska, Kansas, New Mexico, Texas and other western states. Regrettable as it was, the controversy caused new studies and observations to be made and yielded the classic sections of the Cretaceous of the upper Missouri river country, of which the Dakota section is one.

Hayden collected many dicotyledonous leaves from the sandstones along Missouri river, particularly those near Tekamah and in the exposures at Sioux City. In the absence of Dr. Newberry, Hayden sent sketches of these leaves to Prof. Heer of Zurich, who was somewhat surprised at their nature. Heer said there was nothing like these leaves in the European Cretaceous and thought they corresponded best to the lower Miocene of Europe.[41] This started the controversy which did not end until Marcou and Capellini visited the Dakota type area in 1863 and acknowledged the Cretaceous age of the rocks.[42]

In 1857 Meek and Hayden[43] made correlations of their formation No. 1 of Nebraska with sandstones containing dicotyledonous leaves

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[40] Hall, J., Am. Jour. Sci., Ser. 2, Vol. 24, pp. 72-86, 1857; and U. S. 34th Cong., 1st Sess., S. Ex. Doc. 108, House Doc. 135, pp. 126-138.
[41] Heer, Oswald, Proc. Phila. Acad. Nat. Sci., Vol. 10, 1858, pp. 265-266, 1859.
[42] Marcou, J., Bull. Geol. Soc. France, 2 Ser., Vol. 21, pp. 132-146, 1864.
[43] Meek and Hayden, Proc. Phila. Acad. Nat. Sci., Vol. 9, 1857, pp. 129-133, 1857.

in Kansas, on the basis of sections and descriptions received from Major Hawn. In 1858 Meek and Hayden[44] had the opportunity of studying these sandstones near the junction of Grand Saline and Smoky Hill rivers in central Kansas and of visiting other localities mentioned by Major Hawn. For the first time they were assured by direct observation that the Kansas sandstones could be correlated with their formation No. 1 of the Nebraska section. Major Hawn[45] had called the Kansas beds Triassic. Newberry assured Meek and Hayden that the dicotyledonous leaves which they had collected from the Kansas localities were not of Triassic age, as they were much too modern.

Newberry,[46] about the same time, crossed Kansas along the old Santa Fe trail on his route to New Mexico and had opportunity to visit some of the localities near Arkansas river reported by Meek and Hayden and repeated his judgment that the dicotyledonous leaves indicated Cretaceous rocks. Also, as a result of his New Mexico trip Newberry published in 1860[47] a rather lengthy paper in which he refuted Heer's determination of Hayden's collection of leaves from Nebraska. Newberry had a very wide field experience and had seen the leaf-bearing rocks directly overlain by unquestionable marine Cretaceous rocks in many localities from the Atlantic coast to the central interior and in the Rocky Mountain states. His appeal for proper classification was strong, but he realized the prestige of Prof. Heer as a paleobotanist. Heer[48] answered Newberry and maintained the Miocene age of the leaves submitted to him for study. It is evident, however, that he realized the possibility of a mistake, especially as he had only diagrams to study. He made a suggestion that the American geologists might have overlooked the possibility of great thrust faults causing the marine Cretaceous to be superposed on the Miocene. He called attention to the great thrust faults in the Alps, which have caused equally great displacements of strata. Not having had field experience in the central part of the United States, Heer could not realize the fallacy of such a postulation.

In 1863 when Marcou,[49] accompanied by Capellini, visited the Sioux City area and studied other exposures of the Cretaceous along Missouri river, he concluded that the leaf-bearing beds were of fresh water

44 Meek and Hayden, Am. Jour. Sci., Ser. 2, Vol. 27, pp. 31-35, 1859.
45 Hawn, Frederick, St. Louis Acad. Sci. Trans., Vol. 1, pp. 171-172, 1858.
46 Newberry, J. S., Am. Jour. Sci., Ser. 2, Vol. 28, pp. 293-299, 1859.
47 Newberry, J. S., Am. Jour. Sci., Ser. 2, Vol. 29, pp. 208-218, and Vol. 30, pp. 273-275, 1860.
48 Heer, Oswald, Am. Jour. Sci., Ser. 2, Vol. 31, pp. 435-440, 1861.
49 Marcou, J., Bull. Geol. Soc. France, Ser. 2, Vol. 21, pp. 132-146, 1864.

origin, but, as they are overlain by marine Cretaceous without any kind of discordance, that they also must be of Cretaceous age. However, he believed that the series of sands were to be correlated with younger beds of the European Cretaceous, that is, the Senonian of D'Orbigny, or possibly the Turonian. He states also that there are older beds in Arkansas, Texas and Oklahoma (along Canadian river), and he thought these beds to be the same as the green sands of Europe, or Neocomian.

In the meantime Meek and Hayden had restudied the Cretaceous exposures and published their final section of these rocks of Nebraska in 1862.[50] They gave the name Dakota group to formation No. 1 and reiterated their belief in its Upper Cretaceous age. At this time Meek and Hayden thought the Dakota, Fort Benton and Niobrara groups to be the equivalent of the lower or Gray Chalk and upper Green Sand of the British geologists or the Turonian and Cenomanian of D'Orbigny.[51] In commenting on the Dakota, the authors of the name wish it to be understood "that we do not regard the several rocks to which we have applied the names 'Dakota group', 'Fort Benton group', etc., as being always separately and individually recognizable at widely distant parts of the world, nor even in all cases throughout North America".[52] That Meek and Hayden recognized at this early date that the Dakota stage was not a simple or distinct division is indicated in their statement that: "Although we still retain this as a distinct rock, our present impression is that it is probably only a subdivision or member of the Fort Benton group."[53]

Meek was not able to agree with Marcou on the fresh water origin of the Dakota formation. Marcou felt that the presence of the dicotyledonous leaves and the mollusk *Cyrena* (which he called *C. nova-mexicana*) were certain indicators of a nonmarine environment. Meek, however, points out[54] the fact that *Cyrena arenarea* (as identified by Meek and Hayden) occurs with *Pectunculus, Mactra siouxensis* and a *Pharella,* and it cannot be fresh water alone. *Pectunculus* and *Mactra* are marine genera and *Pharella* and *Cyrena* are brackish water genera, hence Meek concludes: "The rock was deposited in a bay or estuary, which must have been alternately brackish and salt enough to sustain marine mollusks. The nature of the sediments composing it, as well

50 Meek and Hayden, Phila. Acad. Nat. Sci. Proc. for 1861, pp. 415-447, 1862.
51 Idem, p. 419.
52 Idem, p. 420.
53 Op. cit., p. 420.
54 Meek, F. B., Am. Jour. Sci., Ser. 2, Vol. 39, pp. 157-173, 1865.

as the numerous leaves and even trunks of trees, at some places found in it, attest the fact of its being a shore deposit."[55] Meek appears to be very definite in his correlation of the Dakota of the Missouri river section, as he says that it is the exact equivalent of the leaf-bearing beds on Raritan river, New Jersey, which form the inferior member of the Cretaceous rocks of that state.

Capellini and Heer[56] published the results of their new studies of the Cretaceous leaves in 1866. The paleobotanists agreed that the Dakota is Cretaceous but maintained that the zones containing the leaves were deposited by fresh water. So far as they were concerned this settled the dispute as to the age of the beds which Heer had first called lower Miocene.

Lesquereux confirmed in 1868[57] the conclusions of Newberry and the other American geologists, when he identified the collections of dicotyledonous leaves from Tekamah and the type area of the Dakota as being of Cretaceous age.

White, in his Geology of Iowa,[58] describes briefly the Cretaceous section and makes three subdivisions "and with no intention of superseding the names in their general application which these gentlemen (Meek and Hayden) have proposed for the more general subdivision of the strata where they are more fully developed."[59] From top to bottom he called these divisions "(3) Inoceramus beds, 50 feet thick, (2) Woodbury sandstones and shales, 150 feet thick, and (1) Nishnabotany sandstone, 100 feet thick." These names did not receive common usage, except locally in Iowa, and have been abandoned because of the priority and more specific application of the Meek and Hayden terms. The type locality of the Nishnabotna sandstone was taken to be along East Nishnabotna river in Page, Montgomery and Cass counties and was thought, at the time it was proposed,[60] to represent beds older than any exposed in the type locality of the Dakota series. The Woodbury sandstones and shales comprised all the beds from the base of the Sioux City section to the calcareous shales containing abundant *Inocerami*. White would have put into one formation the Dakota and lower Benton shales of Meek and Hayden.[61]

55 Idem, p. 172.
56 Capellini and Heer, Mem. Soc. Helvetique des Sci. Nat., t. 22, pp. 1-24, 1866.
57 Lesquereux, L., Am. Jour. Sci., Ser. 2, Vol. 46, pp. 91-105, 1868.
58 White, C. A., Geology of Iowa, Vol. 1, pp. 285-295, 1870.
59 Idem, p. 289.
60 White, C. A., Am. Jour. Sci., Ser. 2, Vol. 44, p. 23, 1867.
61 White, C. A., Geology of Iowa, Vol. 1, p. 291, 1870.

In his report on the Geology of Woodbury county[62] White gives several sections from exposures at or near Sioux City. His section taken at Cedar Bluffs (which is now a part of Stone Park), on Big Sioux river, is also given as a generalized section for the Sioux City area.[63] This section shows 80 feet of Woodbury sandstones and shales and is similar to the Meek and Hayden sections, though somewhat more detailed. The name Woodbury is not used by the Iowa geologists, as by its original definition it did not have stratigraphic value but included two different formations previously divided.

In 1891 the Cretaceous correlation paper by White[64] appeared. Mention is made of the type section, and references are made to the original description by Meek and Hayden and to their general statements concerning the formation elsewhere. At this time there seemed to be no doubt concerning the correlation of the Nebraska Dakota and similar rocks elsewhere. This surety is indicated by the following quotation from White: "The Dakota formation is so well defined that no difference of opinion as to its identity, characterization, and delimitation has ever arisen among geologists who have studied it in the south interior region."[65]

The first indication that the Dakota formation might be much thicker than the observed exposures in the Sioux City area came from the study of well records and cuttings. Meek and Hayden apparently had some such information available, as their section of 1861 gave a thickness of 400 feet for the Dakota. Todd[66] in 1890 gives the records of two wells which are useful in determining the thickness of the Dakota. The well drilled at Ponca, Nebraska, started at 1175 feet elevation and was drilled 698 feet deep. A portion of the log below 80 feet of drift clays is repeated below.[67]

	Feet
Chalkstone, capped with siliceous layers, Inoceramus beds	45
Alternate layers of fine, stratified sand and light and drab clay. A pretty compact stratum with a layer of lignite above, sometimes for a little ways, 6 to 8 inches thick	65
Sand and sandstone. *Dakota*	230
Sandy shale and fine light green clay with grains like "greensand"	35
Rusty, gray, porous limestone, and other limestones which are probably all Pennsylvanian continue to the bottom of the well.	

Todd apparently correlated the upper Chalkstone horizon with

62 White, C. A., Geology of Iowa, Vol. 2, p. 186, 1870.
63 Idem, pp. 196-197.
64 White, C. A., U. S. G. S. Bull. 82, pp. 140-164, 1891.
65 Idem, p. 164.
66 Todd, J. E., Iowa Acad. Sci. Proc., Vol. I, part ii, pp. 13-14, 1892.
67 Todd, op. cit., p. 13.

White's Inoceramus beds, and the balance of the beds down to the limestone would be included in White's Woodbury sandstones and shales, making a total of 330 feet of this formation underlying Ponca, Nebraska. Todd's descriptions of the formations are very interesting, but it is doubtful if there are 230 feet of sand or sandstone in the section, as all other sections in the region do not indicate such a purity of materials. The lowest Cretaceous in the well record, which Todd describes "with grains like 'greensand' ", may have considerable significance. From observations elsewhere the writer believes the grains are glauconite.

A well at Sioux City which starts below the top of the Dakota shows 191 feet of sand and sandstone which Todd[68] calls Dakota; the Le Mars well shows 147 feet of the same material; and it is believed that 109 feet of dark gray sand at Emmetsburg is the equivalent of the Dakota.

Calvin[69] made an important contribution in 1892 when he reviewed the classifications of the Cretaceous of the Sioux City area as used by the U. S. Geological Survey and by the Iowa geologists. Calvin's generalized section of the Cretaceous rocks exposed in the bluffs facing Big Sioux river is given below:[70]

9.	Calcareous beds consisting of chalk and soft, thin bedded limestone, containing shells of *Inoceramus problematicus*, *Ostrea congesta*, and teeth of *Otodus*, *Ptychodus* and other selachians	30 Ft.
8.	Shales more or less unctuous to the feel, somewhat variable in color and texture, containing remains of saurians and teleost fishes, the upper beds sometimes bearing impressions of *Inoceramus problematicus*	40 Ft.
7.	Argillo-calcareous or arenaceo-calcareous beds with much selenite (varying with locality)	20 Ft.
6.	Blue, yellow and red mottled clays (terra cotta clays) with selenite crystals and some streaks of sand	30 Ft.
5.	Band of impure lignite	4 to 6 In.
4.	Shales with usually two, but sometimes more, well-marked thin bands of ferruginous concretionary sandstone ("Buttons" of the clay workers)	16 Ft.
3.	Massive sandstone, mostly soft; but in places containing large concretionary masses several feet in diameter in appearance and hardness resembling quartzite	10 Ft.
2.	Grayish and mottled shales with thin ferruginous bands and arenaceous layers	12 Ft.
1.	Irregular beds of sandstone varying in color and texture and interstratified with thin beds of shale	18 Ft.

The section as given totals 176 feet, the upper 70 feet being younger than Dakota. Calvin[71] states: "Beds 1 to 7 inclusive are the strati-

68 Idem, p. 14.
69 Calvin, S., Iowa Acad. Sci. Proc., Vol. I, part iii, pp. 7-12, 1893.
70 Idem, p. 8.
71 Calvin, op. cit., p. 10.

graphical equivalents of beds near Ponca, Nebraska, which Hayden refers to the Dakota group. No. 8 includes beds that at Ponca and St. Helena have been referred to the Fort Benton group by the same author, and the Inoceramus beds No. 9, are the exact equivalents of the lower twenty or thirty feet of the Niobrara group." Calvin discusses the conditions of deposition of the Cretaceous and concludes that northwestern Iowa was near the shore line of a slowly advancing sea that came from the west. The differences in the character of the beds at Sioux City which Calvin called Niobrara and the beds of the same age at the type locality 85 miles west are due, he thought, to the differences in the position of the shore line. The differences in the lithology of the Dakota are explained in a similar way: "The sandstones and shales of the Dakota group, with respect to the lower portions at least, were accumulated in a rather shallow land locked sea. Currents swept the sand back and forth, sometimes building up, and again tearing down, previously constructed beds, and so produced the fine examples of cross bedding or current structure"; and: "The few molluscan species found in the lower part of the Dakota group indicate the presence of brackish water. The numerous vegetable remains which characterize the group imply that the large volumes of drainage waters which maintained the conditions favorable to the existence of brackish water mollusks, carried not only sand but swept in leaves and trunks of the willow, poplar, magnolia, and other forest trees, from the adjacent lands."[72] The Fort Benton group merely represents a deep or open water sea that developed by a slowly subsiding ocean basin from the conditions described for the Dakota. These interpretations aid Calvin[73] to conclude "that the question of dividing the sediments into distinct groups at all is simply one of convenience" and as "the upper portions of the Dakota merge gradually into the Fort Benton" such divisions, if made, must be purely arbitrary.

Calvin[74] expresses a law which is now generally well understood, though sometimes neglected, that: "Synchronous deposits of the same geologic basin are more likely to present uniform lithological and paleontological characters, if the geologist traces them along a line parallel to the shore of the basin. If the observations are made along the line that is radial to the geologic basin, or at right angles to the trend of the shore, the different parts of absolutely synchronous beds are almost certain to vary in lithological and paleontological characteristics, so much as sometimes to make it appear that different parts of the same bed belong to different geologic epochs."

72 Calvin, S., op. cit., p. 11.
73 Idem, pp. 11-12.
74 Idem, p. 12.

Hicks[75] reported in 1885 the finding of a new locality of Dakota marine invertebrates in southern Nebraska and discussed the "beach structure" of the sandstone. Later he described this locality in "Jefferson county, Nebraska, 5 miles west of north from Fairbury, about 1 mile from the Little Blue river - - - upon the north side of a deep ravine about halfway up the slope. This ravine runs into Whiskey Run, and the latter empties into Little Blue river".[76] White made a study of Hicks' collection and decided the mollusks to be fresh water types. In general, White is skeptical of any marine Dakota, tending to believe at that time that the collections of marine invertebrates from central Kansas, as reported by Mudge, belong to a lower formation, and doubting if the evidence of two or three marine forms from the Dakota of the Big Sioux river area is sufficient to warrant the conclusion that marine conditions existed at that place.

White identified and figured the following species:

Unio barbouri n. sp.
Unio sp.?
Corbula hicksii n. sp.
Goniobasis jeffersonensis n. sp.
Goniobasis sp.
Pyrgulifera meekii n. sp.
Viviparus hicksii n. sp.

Keyes,[77] Calvin[78] and Bain[79] [80] published articles on the Cretaceous of Iowa in the 1890's. Most of this material is a repetition of the articles that have been reviewed, and very little new was added. Keyes called the Fort Dodge gypsum beds Cretaceous, believing they were deposited at the same time as the Niobrara chalks along Missouri river.[81]

Bartsch[82] lists 16 species of leaves from a ferruginous sandstone lens of a shale formation exposed just north of Sergeant Bluff. He suggests that the autumn winds would blow leaves from the upland or intermarsh trees into the marshes, lagoons, bayous and other submerged areas, where the leaves were covered under the sediment of sand and silt brought in by the fall rains.

In 1900 Gould[83] published an extensive review of the Dakota of Kansas and Nebraska. He gives a good historical sketch of the de-

75 Hicks, Proc. Amer. Assoc. Adv. Sci., Vol. 34, pp. 217-219, 1885.
76 White, U. S., Natl. Mus. Proc., Vol. 17, pp. 131-138, 1894.
77 Keyes, C. R., Iowa Geol. Survey, Vol. I, pp. 123-128, 1893.
78 Calvin, S., Iowa Geol. Survey, Vol. I, pp. 147-161, 1893.
79 Bain, H. F., Iowa Geol. Survey, Vol. III, pp. 99-114, 1895.
80 Bain, H. F., Iowa Geol. Survey, Vol. V, pp. 241-299, 1896.
81 Keyes, op. cit., p. 137.
82 Bartsch, P., Bull. Lab. Nat. Hist. S. U. I., Vol. 3, No. 4, p. 178, 1896.
83 Gould, C. N., Kans. Acad. Sci. Trans., Vol. 17, pp. 122-178, 1901.

velopment of the studies on the Dakota and a good bibliography. His references to the type area of the Dakota formation include a review of the literature which has already been discussed in this paper and a very generalized section which he compiled from his own observations and the published sections. Gould finds difficulty in determining the lower limits of the Dakota, as he recognizes the condition in central Kansas where the "Dakota flora" occurs beneath the marine Mentor of Washita age. The top of the Dakota formation is indefinite and indicates a transition to the Benton formation. Gould is "reluctantly forced to the conclusion that any persistent or general division of the Dakota group is not only impracticable, but, in the light of our present knowledge, impossible."[84] As to the origin of the deposits, Gould does not offer any new suggestion but concurs with Lesquereux, whom he quotes as considering the Dakota as a series of deposits made in shallow water near the strand line, and often with the land deposits pushing out into the sea. The flora, according to Lesquereux,[85] has been "derived from trees or groups of trees growing in the vicinity of muddy bottoms, where they have been buried and fossilized."

Gould[86] gave a very general description in 1900 of the Dakota formation of Nebraska, but without adding materially to what was already known. The best part of this paper is his statement of the location of the various types of Dakota in the state. A year later[87] he gave a comparison between the Nebraska and Kansas Dakota and again cited locations and gave some good sections. Very little of the type section is discussed in this paper. However, this is one of the first publications giving a detailed description and correlation of the Dakota formation from Nebraska to Kansas.

The first general geological study made of Dakota county, Nebraska, was published in 1903 by Burchard.[88] In this report Burchard reviews the work of previous geologists, gives records of deep wells, gives several new sections, especially near Homer, Nebraska, and gives a detailed account of the lignite beds. No new conclusions are reached concerning the history of the sediments, as his interpretations are essentially the same as those made by Calvin.[89] Burchard places the division between the Dakota and the Graneros at the base of the Ben-

84 Idem, p. 144.
85 Idem, p. 145.
86 Gould, C. N., Am. Jour. Sci., Ser. 4, Vol. 9, pp. 429-433, 1900.
87 Gould, C. N., Kansas Acad. Sci. Trans., Vol. 17, pp. 122-178, 1901.
88 Burchard, E. F., Acad. Sci. and Letters Proc., Sioux City, Vol. 1, pp. 135-184, 1903-4.
89 Calvin, Iowa Acad. Sci. Proc., Vol. I, part iii, pp. 7-12, 1893.

ton, "at the upper plant bearing sandstone member of the Dakota."[90]

In the comprehensive report by Darton[91] published in 1905 are found the sections and localities of the Dakota formation of Nebraska, much as in previous reports by other authors. Darton emphasizes the irregular contact of the Dakota on the Carboniferous limestones as observed in the southeastern part of the state and infers a marine origin for the Dakota. He says[92] "the contact line between the Dakota sandstone and the Carboniferous beds in eastern Nebraska presents many steep slopes, indicating an irregular shore line against which Dakota sediments were deposited." However, in speaking of the coarse conglomerates and 'peanut gravels' near Cedar Creek, Darton[93] suggests they are "probably marking old stream courses in the Dakota deposition." The general irregularity at the base of the Dakota (and in Nebraska it is in contact with Pennsylvanian or Permian limestones and calcareous shales) becomes obvious when the thickness of the Dakota type of sandstone is observed in the many deep wells of the state. The thickness of the Dakota ranges from less than one hundred feet to about four hundred feet.

In Water Supply Paper 215 Condra[94] describes the Dakota sandstone of northeastern Nebraska and gives several sections of the formation in the type area. He notes the irregular thickness of the formation indicated in the deep wells of the area. One point which he makes that is worthy of note here is his statement that "the component beds of the Dakota formation in this region are not sufficiently continuous, extensive, nor distinctive to afford a basis for subdividing the formation into different horizons."[95]

In his description of the geology of the Elk Point quadrangle Todd[96] uses the previously described sections of the Sioux City and Dakota county areas in his discussion of the Dakota sandstone.

Darton[97] does not discuss the type section of the Dakota formation in his water supply paper on South Dakota. He gives a number of well records which mention the thickness of the formation in adjacent localities and indicate the extreme variability of the sandstone. A point

90 Burchard, Idem, p. 150.
91 Darton, N. H., U. S. Geol. Surv. Prof. Paper 32, pp. 140-144, 1905.
92 Idem, p. 140.
93 Idem, p. 143.
94 Condra, G. E., U. S. Geol. Survey Water Supply Paper 215, 57 pp., 1908.
95 Idem, p. 9.
96 Todd, U. S. Geologic Atlas, Folio No. 156, 1908.
97 Darton, N. H., U. S. Geol. Surv. W. S. Paper 227, 1909.

of interest is the statement that wells drilled at Yankton, South Dakota, pass from the Dakota formation into Sioux quartzite.[98]

From 1910 to the present many papers have appeared by various authors, who have discussed the Dakota sandstone formation of localities in the central interior of the United States. Practically all of these writers have made brief references to the type area of the Dakota formation, without adding to the detailed knowledge or interpretation of the sections. In many cases, however, the interpretations made by the various writers for the Dakota formation in other regions have been helpful in the study at the type locality. For this reason brief mention of such contributions is made here.

Todd[99] reviewed the literature concerning the age of the Dakota stage and reached the conclusion that it is Lower Cretaceous in age. Much of the question as to the age of the Dakota stage arises from studies of the beds in localities other than the type area.

The relationships of the Dakota stage in the Black Hills, in Kansas, in Colorado and other places show that the problem is not simple. It might be said here that this difficulty has arisen from an effort to correlate over too wide an area a sandstone and shale series lying beneath the chalk beds. The paleophysiographical conditions of the interior and the older sea and land deposits varied so greatly that the Dakota overlapped beds of widely different ages or in some cases was nearly continuous with only slightly older deposits. The resulting variations of environment and modes of deposition of the Dakota stage complicate the problem. The question of the real age of the Dakota stage in the many localities is still unsolved, as it was when Todd considered the subject. Unfortunately, Todd failed to clarify the problem, as he denied the possibility of the Dakota stage being of different ages in different localities. To indicate his stand, the following quotations from his summary should suffice:[100]

"From the standpoint of stratigraphy, it is questionable whether much, if any, of the present Dakota sandstone was laid down contemporaneously with any of the marine Upper Cretaceous. No doubt there were terrestrial deposits laid down over the Great Plains, while marine beds, now recognized as Upper Cretaceous, were forming in southern Texas or Mexico; but in the later transgression of the sea northward several feet in thickness of such beds must have been cut

98 Idem, p. 146.
99 Todd, J. E., Kansas Acad. Sci. Trans., Vols. 23 and 24, pp. 65-69, 1911.
100 Idem, pp. 68-69.

away by the wave action and rearranged in the Benton of the Upper Cretaceous, as Grabau argues. This may have removed all which was formed on the land during such transgression, and should it ever be found to be otherwise, still the rational and most convenient place of division would be above the Dakota.

The invertebrate remains of the Dakota are closely akin to those counted Lower Cretaceous, and are quite distinct from those of the Upper Cretaceous. The plant life, also, though less decisive, is in part at least coördinate with that of the beds below rather than with that of those above. The paleontological evidence, therefore, favors the same division as the stratigraphical.

Lithologically, also, the most natural classification will be to put the whole of the Dakota, as originally limited in the Lower Cretaceous. To divide it in most cases brings greater confusion. The division between the Dakota and Benton is not very sharply defined, for it takes a few scores of feet to change from a decidedly sandy formation to one decidedly clayey, several variable thin strata of sand and shale being intermingled between. As it marks the advent of the sea, however, the occurrence of marine fossils assists in the demarkation."

These statements summarize Todd's reasons for placing the Dakota in the Lower Cretaceous.

In a short abstract published in 1913, Keyes[101] gives a new nomenclature for the 'Cretacic' sequence of Iowa. Seven zones are made of the approximately 800 feet of strata, beginning at the top; Niobrara limestone, Hawarden shales, Crill limestone, Woodbury shales, Ponca sandstone, Sergeant shales, and Nishnabotna shales. This section has not been adopted by the Iowa or other geologists, as the names merely duplicate the formations named by Meek and Hayden or do not have stratigraphic value.

Twenhofel[102, 103] has made extensive studies of the Dakota and Comanchean formations of Kansas, bringing to date the previous work on the Comanchean, and making a significant contribution to the paleontological knowledge of the Comanchean. Twenhofel is strongly of the opinion that the 'Dakota' belongs to a series of sands and clays that were deposited as deltas, stream channel deposits, and possibly in littoral or marginal lagoons, and that "parts of the 'Dakota' sandstone of Kansas and the marine strata known as the Kiowa-Mentor

101 Keyes, Science, N. S., Vol. 38, p. 241, 1913.
102 Twenhofel, W. H., Kansas Acad. Sci. Trans., Vol. 28, pp. 213-233, 1917.
103 Twenhofel, W. H., Am. Jour. Sci., Ser. 4, Vol. 49, pp. 281-297, 1920. See also Kans. Geol. Surv., Bull. 9, 135 pp., ills., 1924.

were deposited during the same general interval of time, the former being the continental equivalent of the latter."[104]

In describing the Mentor-Dakota sequence Twenhofel[105] notes that the several marine horizons of the southern part of Kansas drop out northward, "but at least one marine horizon extends as far north as southeastern South Dakota." In making reference to the Dakota of the type area Twenhofel[106] takes the statement of Meek that the Dakota formation is about 400 feet thick, and further states: "From some horizon or horizons of this sequence have been collected the following invertebrates: *Arcopagella? macrodonta* Meek, *Cyrena dakotensis* Meek, *Mactra siouxensis* Meek, *Margaritana nebraskensis* Meek, *Pharella dakotensis* Meek, *Trigonarca siouxensis* Meek. The zone containing the fossils correlates best with the thin sand layers in the upper Dakota of Kansas. The shells may have been inhabitants of brackish water, but not fresh water, as nearly related forms occur in the marine Mentor."

The difficulties of drawing the base of the Upper Cretaceous on the basis of the observations in Kansas and elsewhere are readily appreciated by Twenhofel. If the Cretaceous beds of North America are to be divided into Lower, or Comanchean, and Upper, where should the line be drawn? Twenhofel believes the line should be drawn, so far as Kansas is concerned, between the last appearance of the Washita fauna and the first appearance of the Benton fauna.[107] According to his interpretation this would place the Dakota of Kansas in the Lower Cretaceous. At the same time he recognizes the prevalent opinion, held by some American and European geologists, which regards the Washita as the equivalent of the Cenomanian of the Upper Cretaceous of Europe. Even though Twenhofel bases his separation of Lower and Upper Cretaceous in Kansas on what he believes to be an extensive withdrawal of the sea at the close of Washita time, he realizes this might mean a difference in the exact age for the Washita as compared with the formations separated by a marine withdrawal in Europe.

Berry[108] challenges the statements made by Twenhofel[109] in placing the boundary between the Lower Cretaceous, or Comanchean, and the Upper Cretaceous at the top of the Dakota or the base of the Benton of Kansas. Berry calls attention to the errors which have arisen from

104 Kansas Geol. Surv. Bull. 9, p. 41.
105 Am. Jour. Sci., Vol. 49, p. 286, 1920.
106 Idem, p. 292.
107 Idem, p. 294.
108 Berry, Am. Jour. Sci., Ser, 4, Vol. 50, pp. 387-390, 1920.
109 Op. cit., pp. 294-295.

the confusion about the so-called "Dakota flora." The early collections were made from ferruginous sandstones in Nebraska, Kansas, Oklahoma, Colorado and other states and merely labelled "Dakota sandstone," without notes concerning the stratigraphic position of the sandstone or any of the usual details accompanying a fossil collection. According to Berry, this has caused a large number of species to be included in the "Dakota flora" which in reality come from horizons lower, and in some cases much older, than the true Dakota. One notable example is the Cheyenne sandstone of southern Kansas and the sandstones bearing dicotyledonous leaves below the marine Mentor of central Kansas. Berry bases the "true Dakota" flora on the flora of the Woodbine formation of Texas and corresponding ages elsewhere.[110] The Woodbine flora, he says, is intimately associated with the Benton transgression, while the Cheyenne flora has nothing in common with the "true Dakota" flora. No reference is made to the flora from the sandstones of the Dakota type area.

The same author[111] mentions the typical Dakota in his paper on the flora of the Cheyenne sandstone. He comments: "As originally understood the term Dakota was applied to the pre-Benton Cretaceous, no Lower Cretaceous being recognized in that region. Unquestionably the typical Dakota sandstone represents the littoral or marginal deposits of the transgressing Benton sea - - -."

Stanton[112] recently brought to the attention of geological workers the status of the various problems connected with the Dakota sandstone. It is obvious that the problems have only been scratched on the surface and that much work remains to be done. As this is a general paper, only brief references are made to the type section, but because of the prominence of this paper, a more complete review will be made.

Several lists of fossils collected and identified by Stanton appear for the first time, and for comparative purposes later they are given here. From a locality discovered by Gould near Jackson, Nebraska, the following forms have been recognized:[113]

Ostrea sp.
Trigonarca siouxensis Hall and Meek
Arcopagella? macrodonta Meek?
*Pharella ?
Corbula hicksii White
Martesia ? sp. Casts of burrows in wood
Pseudomelania ? sp.

110 Berry, op. cit., p. 387.
111 Berry, E. W., U. S. Geol. Surv. Prof. Paper 129, pp. 199-231, 1922.
112 Stanton, T. W., Geol. Soc. America Bull., Vol. 23, pp. 255-272, 1922.
113 Idem, p. 256.

*Vivipara hicksii White ?
Volutoderma ? sp.
Vertebra of fish
Vertebra of turtle
Tooth of crocodile

Stanton comments that most of these forms indicate marine waters (except those marked *, which may be either fresh or brackish water) and that the sediments indicate a struggle between sea and land along a low sandy shore with swamps, lagoons and inlets.

From a locality near Beloit and Denmark, Kansas, Stanton[114] collected and identified the following species:

Ostrea sp. Large simple form
Anomia sp.
Modiolus sp. Related to M. filisculptus Cragin
Cervillia sp.
Trigonarca siouxensis Hall and Meek
Cyrena ? sp. Resembles C. dakotensis Meek
Tellina sp.
Corbula sp.
Anatina sp.
Pseudomelania ? sp.
Anchura sp.

From approximately the same horizon in a coal mine shaft two miles north of Denmark, Kansas, the following forms were collected:[115]

Ostrea sp. Small simple form
Anomia sp.
Modiolus sp. Related to M. filisculptus Cragin
Arca sp.
Anatina sp. Same as at Beloit

Commenting on the last two collections, Stanton states: "These fossils show no closer relationships with the Mentor and other upper Comanche faunas than is indicated by the presence of some genera in common. The specific identities all connect it with the upper Dakota fauna of Nebraska."

After reviewing the evidence of the Texas, Colorado, Black Hills and other sections, Stanton[116] concludes: "The encroachment of the sea on the American continent which inaugurated Trinity (earliest Comanche) time was gradually continued throughout Trinity and Fredericksburg time, but at the beginning of the Washita the movement was accelerated without previous reversal and the sea soon reached Kansas and Colorado." Rather than a complete withdrawal of the sea to Texas at the close of Mentor time in Kansas, as suggested by Twenhofel,[117] Stanton believes that the sea merely halted for a time,

114 Idem, p. 260.
115 Stanton, op. cit., p. 260.
116 Idem, p. 270.
117 Twenhofel, Am. Jour. Sci., Ser. 4, Vol. 49, pp. 289-294, 1920.

during which the Dakota was deposited. Because of the conditions in northern Colorado and the Black Hills, Stanton does not believe the Washita sea extended beyond southern Colorado and central Kansas.

Reeside[118] described a small fauna from rocks correlated as Dakota, near Bellvue, Colorado, and adjacent localities. This fauna he believes to be "more like that of the Washita group than that of the succeeding Benton shale, or that of any known Dakota beds, and a correlation based on the faunas must be a correlation with the Washita rather than with the Benton."[119] The fauna is small and lacks some of the most characteristic of the Washita-Kiowa-Mentor species, but it is true that the presence of *Inoceramus comancheanus* Cragin, *Pteria salinensis* White, and *Anchura kiowana* Cragin certainly have a Kiowa-Mentor aspect. The large amount of fish scales and bone material in the collection is more indicative of later Cretaceous or Benton age. Reeside also notes that in Kansas the Washita and Dakota beds are so intimately related that any great difference in age is impossible.

The most extensive contribution to Cretaceous stratigraphy in recent years has been made by Lee.[120] After years of detailed study of sections throughout the western interior and the Rocky Mountain states, Lee was able to make correlations and suggestions concerning the conditions of deposition of sediments which have been puzzling geologists for a long time. Lee stresses the importance of structural relations and believes they are of much more significance than fossils in separating the rocks into systems and series.

Lee uses the name "Dakota group" for the section along the Rocky Mountains, especially at Bellvue, Colorado, and he believes "these rocks form a group, as that term is used both popularly and technically."[121] He recognizes the presence of rocks of both Upper and Lower Cretaceous ages as classified by the U. S. Geological Survey. His belief is best understood by quoting his repetition of his statement made in 1923.[122]

> "There is no single, definite, persistent, and easily recognized sandstone, such as was formerly supposed to exist and was termed the Dakota sandstone. In its place there is a group of intimately related beds, probably even more complicated than the

118 Reeside, U. S. Geol. Surv. Prof. Paper 131, pp. 199-208, 1923.
119 Idem, p. 200.
120 Lee, W. T., U. S. Geol. Surv. Prof. Paper 149, 80 pp., 1927.
121 Idem, p. 25.
122 Idem, p. 25.

correlation lines - - - indicate. Doubtless there are many overlapping lenses that differ slightly in age. The group as a whole is interpreted as the result of accumulation of sediments near the strand line of the advancing sea, and as such it differs in age from place to place by the length of time consumed by the advance of the strand line across the intervening distance."

On another page Lee[123] discusses the general conditions which prevailed at each stage and emphasizes his belief that the Morrison formation of Colorado is Lower Cretaceous in age and that Upper Cretaceous time began with the extensive sea invasion, with the deposition of the conglomerate which he has been able to trace throughout large areas. The variations in the Dakota group as he describes it are due to the slowness of the general advance of the Upper Cretaceous sea, with its many fluctuations and minor retreats. Rocks not strictly marine would be formed along the coastal plain or littoral zones, to be covered later by the oncoming sea. With this understanding Lee[124] "regards the group as the early sedimentary expression of the great marine Cretaceous succession of the West" but "does not correlate its individual beds from place to place with great exactness. - - - Nevertheless, a significant succession is recognizable in many places."

It might be added here that Lee has placed the Washita beds of Kansas in the Upper Cretaceous, partly because he correlated the Washita with the Cenomanian, a part of the Upper Cretaceous of Europe. It is generally recognized in this country that the Washita-Kiowa rocks of Kansas are younger than the European Lower Cretaceous. In the same way, Lee includes the Purgatoire of southeastern Colorado in his "Dakota group." It seems very likely that Lee has given impetus to ideas that have been in the background for a long time and that once given the necessary complete study will aid in the solution of the Dakota problem.

Russell[125] has made the most recent contribution to the general study of the Dakota sandstone. It is his opinion that the Dakota of the Black Hills is older than that of the type locality. He quotes Berry to the effect that the Newcastle member of the Mowry in the Black Hills carries a flora that is older than the type Dakota flora.[126] Russell

123 Idem, p. 19.
124 Op. cit., p. 19.
125 Russell, W. L., Econ. Geol., Vol. 23, pp. 132-155, 1928.
126 Idem, p. 135.

Calvin, Keyes and others describe the occurrence of boulders containing Benton, Niobrara and younger Cretaceous fossils in the glacial drift of various parts of Iowa.

Considerable time has been spent in the field endeavoring to locate outcrops from which the "Mentor fauna boulder" might have been derived, but so far the search has been unsuccessful.

concludes that the condition of deposition caused an overlap of the Dakota formation from the Black Hills eastward to northeast Nebraska and northwest Iowa and that the sediments were derived from the east. He uses the direction of inclination of foreset beds in the cross-bedded zones for the principal evidence. In the Black Hills, he says, the oblique lamination of the Lakota, Fuson and the so-called Dakota sandstones have a marked northwest dip, indicating a source of the sediments to the southeast. The thickening of the Graneros from 50 or 100 feet in northeast Nebraska to 1000 feet in the Black Hills is also used as evidence of the eastward migration of the shore-line. Russell is convinced that the Dakota is extremely lenticular, so much so that it could not be a good aquifer, and gives as one of his reasons that "most of the Dakota strata are of terrestrial origin."[127] However, marine sands, possibly as littoral bars, barrier beaches and such, must have been common during this time, for Russell[128] says that the upper Dakota beds "are formed as overlaps or oblique transitions along the shores of an advancing sea, and the topmost strata are much younger towards the east - -."

The discussion of Russell's paper by Piper[129] sets right some facts. Piper is of the opinion that the Dakota sandstone lenses have fair continuity when understood in three dimensions. He points out the wide variety of environmental conditions of deposition, saying they "are river channel, river flood plain, tidal swamp, beach and shallow marine sediments transported by westward-flowing streams and deposited along and adjacent to a strand line which migrated progressively northward and eastward."[130]

In December, 1926, the writer[131] presented a short paper to the Paleontological Society at their Madison meeting, describing the occurrence in the Kansan glacial till of western Iowa of cobbles of a red ferruginous sandstone containing a marine fauna of Mentor aspect. The physical character of the sandstone of these cobbles is very similar to that of zone 6a in Section 1 at Sioux City, described in the present paper. The Mentor fauna is also closely related to the invertebrates occurring in zone 6a of the section just mentioned. Similar erratics have not been reported previously, although many short papers by

127 Russell, op. cit., p. 151.
128 Idem, p. 151.
129 Piper, Econ. Geol., Vol. 23, pp. 683-696, 1928.
130 Idem, p. 686.
131 Tester, Bull. Geol. Soc. Am., Vol. 38, p. 233, abs., 1927.

CHAPTER IV

THE USE OF ROCK TERMS FOR THE DAKOTA

It is evident from the various quotations in the foregoing pages that confusion exists as to the kind of term which should be applied to the rocks which comprise the sandstones, shales and other types of rocks named Dakota by Meek and Hayden.

The original definition of the rocks as given by Meek and Hayden[132] used the term *Dakota group,* a part of the "lower series" of the "Cretaceous formation." The "lower series" included the Dakota group, Fort Benton group and Niobrara division or group. The authors of the Missouri section do not define their understanding of the terms *group, formation* or *series.* It is apparent from their application that the term series denotes rocks of like paleontological characteristics, or at least rocks with a variable fossil content, but one distinctly different from the fossils of the overlying and underlying series. The term group apparently is used by Meek[133] to designate a sequence of rocks lithologically similar, or if dissimilar or of non-persistent zones, the sequence is distinct from the overlying and underlying group.

The term *system* of rocks or *period* of time is widely accepted and used, and there is no need to vary from the rule. To speak of the Lower Cretaceous *Series,* as used by the U. S. Geological Survey, would not be in accordance with the method of applying geographic terms to rock divisions. The use of lower, middle and upper as applied to various systems is merely a convenience and does not justify the designation of the term *series.* A series of rocks might represent, in the writer's opinion, the lower and middle, or the early and middle parts of a system; or the early part of a system might be composed of more than one series.

The term *group,* however, is used in different ways. The United States Geological Survey[134] uses the term to designate "several formations assembled into a group", and a formation is described as a division of a series, the series being a division of a system. The U. S. Geological Survey does not use the term *group* in the same sense as it

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[132] Meek and Hayden, Phil. Acad. Nat. Sci. Proc., Vol. 13, pp. 415-447, 1862; Meek, F. B., U. S. Geol. Surv. Terr., Vol. 9, p. 25, 1867.
[133] Meek, Idem, p. 25.
[134] Wilmarth, U. S. Geol. Surv. Bull. 769, p. 4, 1925.

uses *series,* even though it may appear that the two are synonymous, from the fact that several formations may be grouped either as a series or as a group. The term *group* really means, in their usage, a sequence of formations of smaller magnitude than a *series.* By eliminating this overlap of words, either *group* or *series* could be freed and used for the rock equivalent of *era.* As considerable usage now demands the word *group* for the rocks of an *era,* it is logical that this change be accepted.

It seems desirable that a standard system be used for rock divisions. The binomial system now in use by many writers might be the most satisfactory. The literature is so thoroughly saturated with a variety of usages of some terms that many argue that it is impossible to change. To the writer this is one of the strongest arguments for the standardization of terms. The confusion made in the past does not justify such a continuation, and no time is better than the present for a correction. The usage of terms as applied to the Dakota sandstone is a strong example of the lack of standardization. The Meek and Hayden definition used the term *group.* Other writers have used *series, stage, formation,* and many merely used *Dakota sandstone.* The various terms that have been applied to the Dakota by a number of writers and state publications are indicated below.

Group

Meek and Hayden, U. S. G. S. and other articles, 1866-1876.
King, U. S. G. S. 40th parallel, Vol. I, pp. 298-300, 1878.
Calvin, Iowa Geol. Survey, Vol. I, p. 149, 1893.
Dana, Manual of Geology, p. 815, 1895.
Logan, Kansas Survey, Vol. II, p. 200, 1897.
Gould, Kansas Acad. Sci. Trans., Vol. 17, p. 123, 1900.
Le Conte, Elements of Geology, 5th ed., p. 491, 1903. Uses Dakota *Group* and Dakota *Epoch.*
Lee, U. S. G. S. Prof. Paper 149, p. 25, 1927.

Series

Grabau, Textbook of Geology, Vol. II, p. 686, 1921.

Stage

Bain, Iowa Survey, Vol. V, p. 255, 1896.
Bain, Iowa Survey, Vol. VIII, p. 328, 1898.
Scott, Introduction to Geology, p. 475, 1904.
Keyes, Iowa Survey, Vol. XXII, p. 344, 1912.

Formation

White, U. S. Nat'l Museum, Vol. 17, p. 131, 1894.
Darton, U. S. G. S. Prof. Paper 32, pp. 165-169, 1905.

Chamberlin and Salisbury, Textbook of Geology, Vol. III, p. 144, 1906.
Todd, Kans. Acad. Sci. Trans., Vol. 23, p. 68, 1909.
Lee, U. S. G. S. Bull 341, pp. 320-321, 1909.
Moore, Kansas Survey Bull. 6, p. 81, 1920.
Reeside, U. S. G. S. Prof. Paper 131, p. 199, 1923.
Schuchert, Textbook of Geology, Vol. II, p. 558, 1924.
Twenhofel, Kansas Survey, Bull. 9, 1924.
Rothrock, Oklahoma Survey, Bull. 34, p. 49, 1925.
Gould, Oklahoma Survey, Bull. 35, 1925.
Miller, Historical Geology, p. 270, 1928.

Sandstone

Berry, U. S. G. S. Prof. Paper 129, pp. 158 and 199, 1922.
And many others.

In addition many writers have used Dakota without any other term, speaking of it as 'the Dakota'. Some writers, while avoiding a rock term, mention the Dakota *epoch*.[135]

Lee[136] recently described a section as the Dakota *Group* and says he "believes that these rocks form a group, as that term is used both popularly and technically." The writer presumes the technical use is in the sense of the U. S. Geological Survey usage, or as several formations, and probably as a subseries.

The lithology of the Dakota, the distribution of the various zones, the stratigraphic range and the interpretations made by the writer, all suggest that the term *stage* be used to designate the sandstones, shales and clays exposed near Dakota City, Nebraska, and described by Meek and Hayden as the Dakota Group.

Geologic events which are of considerable magnitude, and which have some effect over a large area, or which constitute a normal progression of rocks, are considered responsible for the deposition of rocks comprising a *stage*. The widespread marine advance, with its shoreline variations due to minor retreats and advances of the waters and to the lands being built out into the ocean, or the migration of faunas and shifting of ocean currents, all have their effect on the character of the rocks. The rocks deposited under such conditions on an extensive scale, as they were during Dakota time, are classed as a *stage*. It might be said that a *stage* is indicative of a set of conditions of rock deposition rather than of a distinct lithological or paleontological division.

135 Hills, R. C., Elmoro folio (No. 58) U. S. Geol. Surv., 1899.
Cleland, Historical Geology, p. 517, 1925.
136 Lee, U. S. G. S. Prof. Paper, 149, p. 25, 1927.

In this paper the term *Dakota Stage* for the rocks, or *Dakota Age* for the time, is used hereafter. It should be understood, then, that the writer does not conflict with the classification by Lee[137] in the rank which the Dakota rocks hold in the aggregate of the Cretaceous section, but that he merely uses *stage* instead of *group,* since the latter term is better used as the rock equivalent of *era.* Thus a *stage* becomes a *subseries* or several *formations* so closely related that they should be held together and still kept as divisions of a series.

[137] Op. cit., p. 25.

CHAPTER V

DESCRIPTION OF THE EXPOSURES IN THE TYPE AREA

At the present time the finest exposures of the Dakota stage are to be found at Sioux City, Iowa, and its suburbs. This includes the Prospect Hill section, the exposures at the Sioux City Brick Company pits, the bluffs along Big Sioux river just south of the west entrance to Stone Park, and several other minor or small outcrops.

Other excellent sections can be observed at Sergeant Bluff, south of Sioux City; the old Crill Mill section about seven miles south of Westfield, Iowa, in section 32, township 91 north, range 48 west; the several sections in the vicinity of Homer, Nebraska; the Aowa creek exposures near Ponca, Nebraska; and many others, especially down Missouri river between Homer and Tekamah, Nebraska.

The section as exposed in the Sioux City Brick Company pits is given first as it can be studied readily. The face is fresh from frequent excavation and is typical of the formations of the Dakota stage. This section is complete, with the exception of the lowest clay members. The best invertebrate fossils collected by the writer came from this pit, and in addition it has yielded some excellent fossil leaves.

SECTION 1. *Pits of the Sioux City Brick Company at Riverside, west part of Sioux City, Iowa, along the South Dakota branch of the C., M., St. P. & P. RR. East side section 23, T. 89 N., R. 48 W., Woodbury county; elevation of top of zone 6a approximately 1125-1130 feet.*

ZONE		FEET
	Top of section, glacial drift and loess	
10	*Limestone,* chalky and argillaceous (marl-like), buff to gray color. Contains abundant *Inoceramus,* fish scales and microscopic Foraminifera. Grades downward to a calcareous shale. In thin sections the rock is extremely fine-grained, calcitic and kaolinitic. The Foraminifera show coarser calcite in outline and cavity fillings. Bands of limonitic iron oxide surround linear masses of fine calcite, the bands dividing and joining to give a cellular structure to parts of the rock. Exposed	15
9	*Sandstone,* gray, medium- to fine-grained, dense, micaceous, and very firmly cemented by calcite. Contains large amount of organic material, chiefly fragments of fish scales, teeth and spines. Fragments of *Inoceramus* shells showing prismatic calcite are common, and numerous casts of small pelecypods *(Callista?)* are seen on weathered surfaces. Weathered rock is gray to buff in color and shows prominent thin lamination with cross-bedding and ripple marks. The thin section examination shows the high percentage of calcite present as a cement and the abundance of glauconite. Other constituents include sericite, grains of quartzite, pyrite, zircon, basic feldspars, tour-	

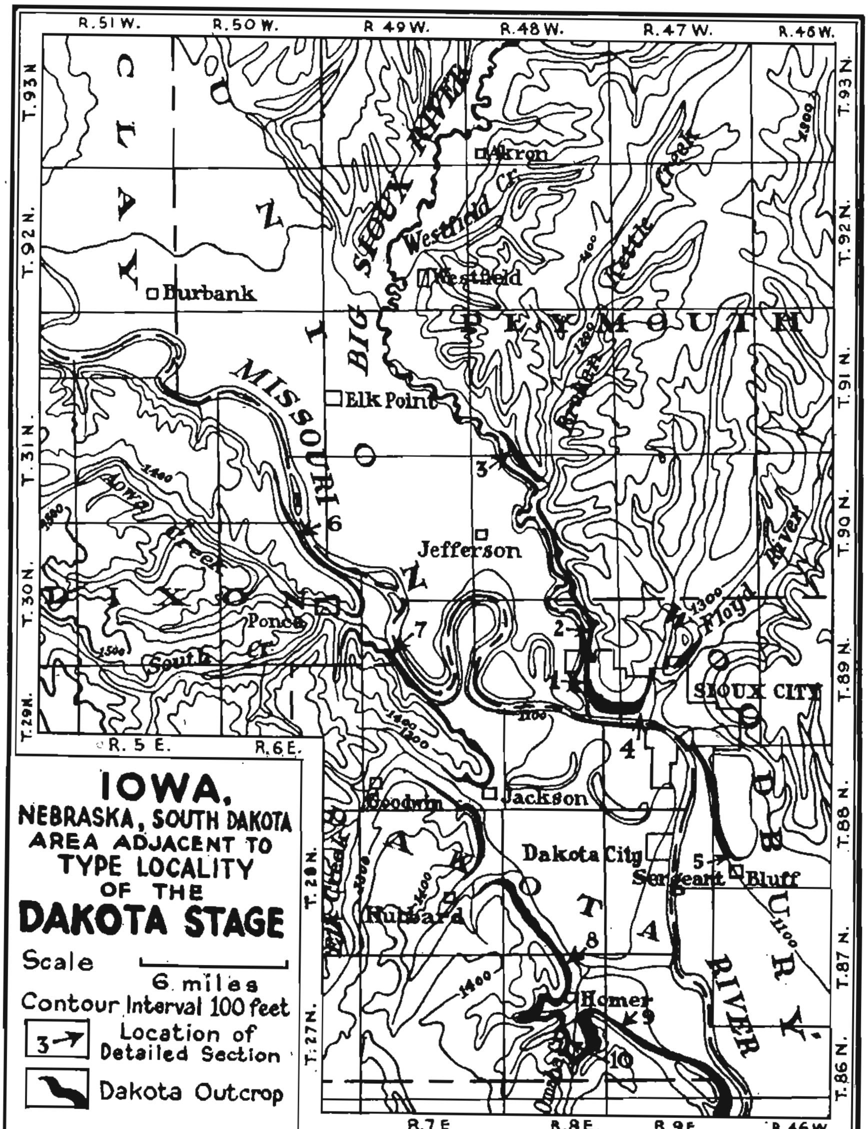

FIG. 25.—Map of the area adjacent to the type locality of the Dakota stage. Modified after Todd.

ZONE		FEET
	maline and hornblende. About 60 per cent of the grains are angular, 30 per cent subangular, 5 per cent curvilinear, 5 per cent subround. In dilute acid 36.4 per cent is soluble	2–3
	Photomicrograph, Plate III, Fig. G (Ts-07044).*	

* Ts 07044 refers to thin section in the rock collection at the University of Iowa.

ZONE		FEET
8	*Shale,* argillaceous, blue-black, evenly bedded, but with many lenses of siltstone that are irregular and that show oscillation ripple marks. Glauconite in siltstone, and occasional fragments of fish scales and bones and imperfect pelecypod casts	22–25
7(b)	*Sandstone,* buff-gray, well cemented by calcite, thin bedded and weathering in thin wavy plates exposing imperfect internal molds of small pelecypods	¼–⅔
7(a)	*Sandstone,* gray, fine-grained, with many bands of large hard, dense calcareous concretions. Base of this zone is especially concretionary, with much iron oxide cementing the sand and lignitized wood	7–8
6(c)	*Shale,* gray, thin laminæ, much selenite and fragmental plant remains	10–12
6(b)	*Sandstone,* yellow and gray, friable, with varying amounts of iron oxide. Very fine-grained; practically a siltstone. Laminæ cross-bedded and variable in thickness and extent. Much shale in thin wavy lenses. Gypsum is present in shale	5–6
6(a)	*Sandstone,* gray, buff to dark red, depending on character of cement. Normally it is cemented by calcite like zone 9 but iron oxide replaces the calcite and changes the character of the rock. The maroon, chocolate, brown, or yellow color of the iron cemented portion differs, depending upon the amount of weathering. Medium- to fine-grained, dense and resistant to erosion. This zone is fossiliferous and contains marine mollusks and abundant fragments of leaves and stems. In the calcitic phases the presence of the shells can scarcely be detected. Considerable secondary gypsum (selenite) occurs in small fractures and as replacements in shells. Pyrite is also commonly associated with the concretions. Glauconite is moderately abundant in this rock. 29.6 per cent of original material soluble in dilute acid	1¾–2
	Photomicrograph Plate III, Figs. A, B, C, D, E, F, H, I. Minerals: Glauconite (Biref .009-.010) R.I.—1.55 to 1.56, Zircon (some altered), Hornblende, Tourmaline, Mica (Muscovite), Magnetite, Ilmenite (rare), Leucoxene, Garnet (rare), Pyrite, Feldspars (several varieties, including a few very basic ones, and many highly weathered with development of kaolinite along cleavage planes), Chlorite (?) (probably secondary alterations product), Sillimanite, Quartzite (abundant), Iron oxide cement. Slides of the calcitic phases show extensive alterations with iron replacing calcite with the development of pseudomorphs of hematite (?) after calcite. Also many of the feldspars show alteration with development of calcite. Fossil List: *Turritella kansasensis* Meek, *Margarita* sp., *Cardium* n. sp., *Corbicula (?) subtrigonalis* Meek, *Cyrena dakotensis* Meek and Hayden, *Mactra siouxensis* Meek and Hayden, *Protocardia texana* Conrad, *Trigonarca salinaensis* Meek, *Trigonarca siouxensis* (?) Hall and Meek, Fish bones, Leaf fragments, Cones.	
5	*Shale,* dark blue-black, thin-bedded and fissile. Contains considerable selenite in small crystals and rosettes, all of which may be secondary. Locally some thin brown concretionary bands of arenaceous and clayey materials. Grades upward to sandstone with large amounts of selenite near base of zone 6(a)	8–9
4	*Sandstone,* gray, very fine-grained, micaceous, has many minutely cross-bedded zones 6 to 8 inches thick. The foresets of these zones have differing directions of inclination, though the easterly directions prevail; in order of numbers the direction of foresetting is, first, southeast, second east, third northeast, and least numerous to northwest. In the upper three feet (4b) are numerous thin variable and disconnected bands of impure lignite and fire clay, and much nodular pyrite. This material appears as very local fillings of depressions and vertical cracks or joints in the soft sandstone	4½–6
3(c)	*Sandstone,* buff, medium fine-grained, massive beds	2–2½

Zone		Feet
3(b)	*Sandstone,* gray, fine-grained with many thin wavy bands of gray clay. A few irregular concretionary zones	5–6
3(a)	*Sandstone* and *siltstone,* with bands of lignite, four being ⅛ inch or less in thickness	1
2	*Lignite,* poor grade, grading downward to impure fire clay. Thickness appears uniform throughout exposure except for irregular base with a variation of 2 or 3 inches. Sharp contact at top	1–1¼
1	*Shale,* very argillaceous, gray to blue-black. Texture is variable horizontally. Some fine alternation of clay with silt and sand. The upper 4 to 6 feet is usually very free of sand, plastic or unctuous, massively bedded with conchoidal fracture	15–16
	Total in section	135

In 1928 the lower pit exposing zone 1 was filled with water to within one foot of zone 2, the lignite.

Zone number 10 belongs, without much question, to the Greenhorn formation as previously described. It is possible that zones 9 and 8 also are a part of the same formation, but there is very little change in lithology from the underlying sands of zone 7. There is very little information to use as an exact basis of division between the Dakota and Colorado stages. Zone 8 shows small oscillation ripples and contains glauconite in the siltstone lenses. These two features are interpreted as indicators of shallow to moderately deep marine waters in a place which normally received deposits of mud; temporary shifts of shore currents or flood conditions of the feeding streams deposited a silt or fine sand. Apparently the conditions of deposition of zone 9 were very little different from those of the deposition of the siltstone layers in zone 8. The age of zone 9 is more definite as it carries casts and fragmentary shells of characteristic Greenhorn invertebrates. Zone 7, and the lower part of the section taken as a whole, is only slightly different from zones 8 or 9, but when compared in detail the upper members indicate slightly more stable conditions. For example, the calcitic concretionary bands of 7a, 7b, and even 6a, and the thin fine-grained sandstone layers of 4 are all comparable to zone 9. The interbedded shales and clays are in many cases nearly the same as the shale of zone 8, but a greater thickness of shale was accumulated with thin lenses of sand interfingering. Conditions were still unsteady, with shifting of currents near shores, but more stable than the conditions indicated by the lower part of the section.

Where then should the line be drawn separating the Dakota stage from the Graneros formation? In such a section, with apparent repetition of conditions, but at the same time with the introduction of new features or indications of gradual changes of environment, the

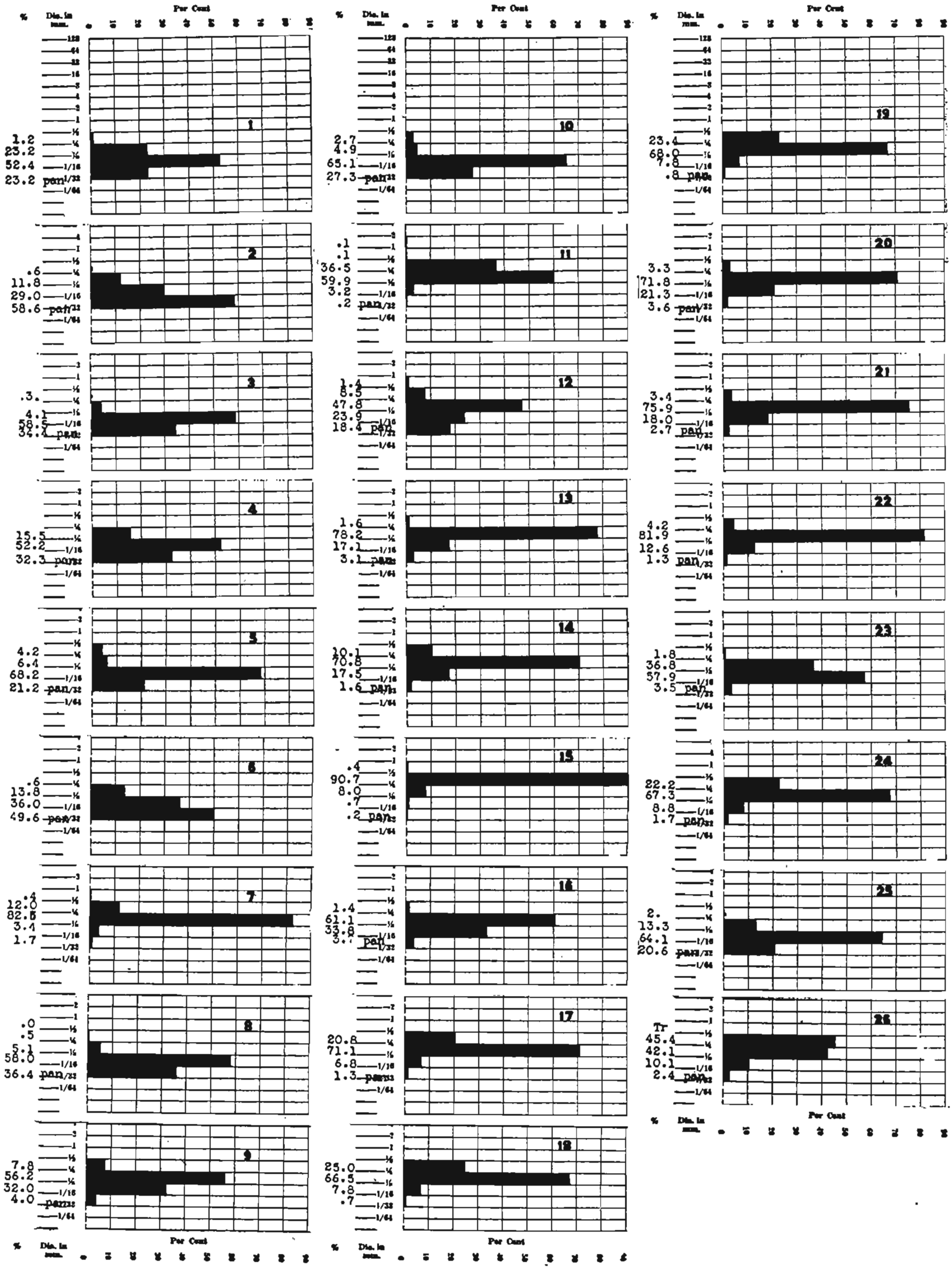

FIGURE 26

writer believes that any division will be purely arbitrary and probably unsatisfactory. There appears to be a transition from the more typical Dakota of zones 3, 4, 5 and 6, to the typical Greenhorn of zone 10. However, the best division, in the writer's opinion, between the Dakota and Graneros is to be found at the base of zone 8.

Further comment on the character of the Dakota will be made after other sections in the area are described.

SECTION 2. *Section 11, T. 89 N., R. 48 W., Woodbury county, Iowa, west of Sioux City in the bluff facing Big Sioux river at old quarry site south of west entrance to Stone Park. Elevation at normal water level approximately 1102 feet.*

ZONE		FEET
13	*Loess*	5–30
12	*Limestone,* chalky and argillaceous, gray, weathering to a dirty buff color. Thin beds 2 to 10 inches thick interbedded with calcareous shale. Contains much secondary calcite in fractures and joints. *Inoceramus* abundant. This is undoubtedly Greenhorn. Lower part is shaly and grades downward into zone 11	12–14
11	*Sandstone* and *siltstone,* gray to buff, fine-grained, iron oxide and clay cement. Has very irregular bedding with wavy shaly bands. In upper part is a silt and more argillaceous and grades into zone 12. In lower part of zone small cross-bedded zones are common with oscillation ripple marks and small mud cracks. Has much selenite in thin layers between wavy layers of siltstone. Erosion channels a few inches deep in thin alternating clay and sand layers are filled with well sorted sand. Sands and clays contain fragmental plant materials	8–10
10	*Shale,* gray, carbonaceous, fissile, gypsiferous. No fossils observed	10–11
9	*Sandstone,* yellow to buff, very fine-grained, non-calcareous, chiefly clay binder. Micaceous, quartz sand with some gypsum, weathered amphiboles, and very few accessory minerals	3
8	*Shale,* gray, carbonaceous, fissile, with selenite. Grades upward to a siltstone with thin alternations of sandstone	6½–7
7	*Sandstone,* yellow to buff and gray, fine- to medium-grained, friable. Contains gypsum and some fresh sulphur; much clay as binder with varying amounts of iron oxide. Weathers as a massive bed, though a close inspection shows indistinct bedding planes and small cross-bedded zones. The top of the zone has a cap of red-brown fine-grained sand with a gnarly concretionary development which is more resistant to weathering and makes a prominent ledge 6 to 10 inches thick. This part of outcrop contains a small amount of greenish brown, partly decomposed glauconite. This may be the equivalent of zone 6a of Section 1. Three feet below this ledge is a 3-inch layer of impure lignite and clay with many fragments of leaves, stems and plant material. Contact with	

FIG. 26.—MECHANICAL ANALYSES OF SEDIMENTS IN TYPE AREA

No. 1. Section 1, zone 6a.
No. 2. Section 1, zone 6b.
No. 3. Section 1, zone 4a.
No. 4. Section 1, zone 4b.
No. 5. Section 1, zone 3b.
No. 6. Section 2, zone 2.
No. 7. Section 2, zone 4.
No. 8. Section 2, zone 5.
No. 9. Section 2, zone 9.
No. 10. Section 4, zone 1.
No. 11. Section 5, zone 10.
No. 12. Section 6, zone 1.
No. 13. Section 6, zone 2a.
No. 14. Section 7, zone 4.
No. 15. Section 8, composite.
No. 16. Section 9, composite.
No. 17. Section 10, zone 1.
No. 18. Section 10, zone 2.
No. 19. Section 10, zone 3.
No. 20. Section 10, zone 4.
No. 21. Section 10, composite lower part zone 6.
No. 22. Section 10, composite upper part zone 6.
No. 23. Section 10, zone 8.
No. 24. Section 11, zone A near base.
No. 25. Section 11, zone C, near top of older part.
No. 26. Four and one-half miles west of Decatur, Nebraska.

ZONE		FEET
	zone 6 uncertain but grades into shale with thin sandstone layers	10–11
6	*Shale,* with thin sandstone layers, and grading upward to sandstone of zone 7. Where sand content is lower the shale is gray to black, carbonaceous and with fragmental plant material. Weathers fissile. In upper part contains considerable selenite and many pyrite concretions ...	8–9
5	*Sandstone,* gray to buff, fine-grained, weathers as a single bed but in detail the generally horizontal laminæ show small northeast and northwest trending cross-bedded zones. Micaceous, abundant plant fragments	7–8
4	*Sandstone* and *clay conglomerate,* with fragments of lignite reworked into sand. The sand is medium- to fine-grained with small amount of clay binder. The clay pebbles range between 16 and 8 mm. and are gray and thinly laminated and usually occur in a zone with a thin discontinuous clay layer. The clay pebbles were partly indurated when deposited. The contact with zone 3 is uncomformable in this section ..	3–4
3	*Shale,* gray turning to brown at lower contact. Carbonaceous and fissile in upper part	5–6
2	*Siltstone,* with many thin alternating layers of shale and in irregular zones. Siltstone is buff to brown, major grade smaller than 1/16 mm. with a few grains nearly ½ mm. diameter. Quartz is dominant but with a clay binder. Most grains very angular, with appearance of fresh fracture chips. A few of larger grains show small amount of wear, falling in the subangular and curvilinear groups. The clay is iron stained when occurring as a binder and as thin laminæ is gray	7–8
1	*Sandstone,* with thin shale layers interbedded. Sand is gray, medium- to fine-grained. At top is a 1- to 1½-foot zone of hard calcite- and hematite-cemented layer of concretions, more or less continuous. Where the sand is iron-oxide-cemented, glauconite appears more abundant, although it occurs throughout the section. Much carbonized plant material scattered throughout zone, especially in the concretionary masses ..	5–6
	Covered, slope, below road level but indicates an alternation of thin-bedded sandstone and shale	15
	Big Sioux river level—elevation approximately 1,102 ft.	
	Total in section, average	105

As in Section 1, the place of separation of the Dakota and Graneros is uncertain, but for similar reasons it is placed at the base of zone 8. The sandstone of zone 11, Section 2, is thicker than the top sandstone of Section 1, but it has many of the same characteristics, and the stratigraphic relations with the overlying chalky or marly limestone are almost identical. In Section 2 the base of the Graneros is approximately 15 feet higher in elevation than in Section 1.

SECTION 3. *Section 32, T. 91 N., R. 48 W., Plymouth county. Road and river exposures facing Big Sioux river, near wagon bridge crossing about 7 miles south of Westfield, Iowa. This is probably the locality of the Crill Mill section of Bain.*[138]

ZONE		FEET
15	*Limestone,* buff to gray. Upper part thinly bedded, lower part soft and chalky and weathers like a buff shale. Contains many *Inoceramus* and small Foraminifera	12
14	*Shale,* gray-black, carbonaceous, weathers fissile. Upper 4 to 5 feet is calcareous and grades into lower part of zone 15. Very little sand in main part of zone. Contains small selenite crystals which are imbedded in fresh shale, making crystal impressions. Also some secon-	

138 Bain, Iowa Geol. Survey, Vol. VIII, p. 328, 1898.

Zone		Feet
	dary gypsum developed along fracture and joint zones. The contact with zone 13 is fairly distinct, but the shale contains a good deal of sand. This probably is due to a certain amount of reworking of the top sandstone layer of zone 13. This is a typical Graneros shale	35
13	*Sandstone*, gray, fine-grained, with layers which are typical siltstones. Some thin iron oxide concretionary zones though major part of member is clay bound. Upper one foot is a prominent layer of medium-grained friable yellow sandstone. Much dicotyledonous leaf material throughout zone	18
12	*Sandstone* and *shale*, chiefly micaceous sandstone, grading to siltstone in thin beds with interbedded even layers of shale ¼ to 1 inch thick. Near center of member a red and brown iron concretionary zone 6 to 8 inches thick makes a prominent outcrop. Some of these concretions are surrounded by more friable sands, and the glauconite is more abundant in the loose sands. Dicotyledonous leaves and fragments occur throughout. In local zones of member much carbonized wood and pyrite occurs	8
	Photomicrograph, Plate III, Fig. J. (Ts-07045).	
11	*Shale* and *sandstone*, interbedded, dominantly shale, gray in thin beds. Sandstone very fine-grained and similar to that of zone 10	3
10	*Siltstone*, grades to fine-grained sandstone; gray to yellow	2
9	*Lignite*, poor grade, has clay layers at top	¼
8	*Shale*, black, carbonaceous, weathers fissile, becomes sandy toward base with much fragmented plant material	3–4
7	*Sandstone* and *siltstone*, gray to buff, clay binder, many thin zones of concretions at base. Upper part has many lenses of siltstone with irregular bands of clay	5
6	*Sandstone*, gray to yellow, fine-grained, micaceous, thin even beds. Iron oxide cement differs in amount, producing yellow and more resistant layers. Concretionary zone at base. Fragmental plant remains occur throughout, in laminæ ⅛ inch apart	14
5	*Sandstone*, buff to brown, fine- to medium-grained, iron oxide and clay cement. Grains principally angular	2
4	*Sandstone* and *shale*, largely a siltstone, interbedded in thin even layers. Much fragmental plant material and in silt or shale zones occasional leaf impressions	6
3	Mostly covered and slumped, except at base where a gray shale with small sandstone concretions may be seen	2
2	*Lignite*, poor grade, cubic fracture. Contains pyrite nodules and carbonized wood	⅝
1	*Shale*, carbonaceous, grading upward into shaly lignite	1–2

The top of the Dakota stage in this section is placed at the base of zone 14. There is less difficulty in making the division between the Dakota and Colorado stages in this section than in any other outcrop in the Sioux City area. The lithologic change is more abrupt than is usually the case. Even with such appearance at the outcrop the base of the gray shale of zone 14 is somewhat sandy and indicates a certain amount of reworking of the sandstone layer at the top of zone 13.

Zone 12 probably is the equivalent of zone 6a of Section 1. The lignite of zone 9 of this section occupies a stratigraphic position nearly the same as the lignite of zone 2, Section 1, but the latter section has a larger thickness of sandstone and siltstone than Section 3. Section 1 probably was nearer the mouth of a distributary channel or in a more favorable position to accumulate littoral bars. Section 3, it appears, was more removed from the shore or in more quiet water for the major part of this period of sedimentation.

SECTION 4. *Sioux City, Iowa, one-eighth mile west of north end combination trolley and highway bridge across Missouri river and at foot of Prospect Hill. Elevation base zone 1 approximately 1,120 ft.*

ZONE		FEET
5	*Sandstone* and *siltstone*, buff to yellow, thin wavy beds of paper thickness, gray clay interlaminated. Some discontinuous concretionary zones with thin layers dark brown iron oxide	7–8
4	*Sandstone*, buff to yellow, very fine-grained, thin and wavy bedding. Lower part concretionary and contact with zone 3 irregular.	
3	*Siltstone* and *shale*. This is a very irregular zone and is non-persistent within 100 feet of outcrop. Upper part chiefly siltstone grading coarser into overlying member 4. Lower part mainly shale and tough gray clay containing dicotyledonous leaves and much fragmented vegetable material. In central zone are many thin concretionary bands with concentrations of iron oxide in horizontal planes. Base unconformable with zone 2 with the development of iron concretions at contact	11–12
2	*Sandstone*, buff, fine-grained, grading to siltstone in upper part. Lower part more or less homogeneous. Base of member indistinct except as marked by poorly preserved oscillation ripple marks. Iron oxide is concentrated in thin zones ⅛ to ¼ inch thick which are parallel to the ripples	8–10
1	*Sandstone*, light gray to buff, fine-grained, micaceous, lower part in thin layers, upper part with numerous horizontal bands of brown-red concretions	10–11

Section 4 probably is one of the classic exposures studied by Meek and Hayden, Marcou, Calvin, Bain and others who have made observations in the Sioux City area. Judging from descriptions by the early workers, this section was much better exposed 25 to 50 years ago than it is now. Years ago the main current of the Missouri was swinging against the bluff at this point, but due to the building of bars upstream the main channel cuts against the bank at the present time about 1000 feet downstream. Filling by man has aided in the building of a river flat between the present exposure and the river's edge. Slumping and the growth of brush has obscured a part of the old sandstone bluff as pictured by Bain.[139] From this exposure some of the early collections of dicotyledonous leaves were made, and it is probable that most of them came from the lower part of zone 3 of the writer's section.

Attention should be called to the remarks concerning the iron oxide concentration which is very closely related to the ripple mark zones and minutely cross-laminated parts of the sandstone. In zones 1 and 5 truncation surfaces developed by wave or current action show a con-

[139] Bain, Iowa Geol. Survey, Vol. VIII, p. 267, 1898.

centration of iron oxide which penetrated a depth of only two or three grains, or which may be wavy and may cement the sand one-half to one inch below the old surface. In the case of ripple marks superposed on older ripples, with intervals varying from a fraction of an inch to two or three inches, a similar condition of concentration can be observed. The facts that such a concentration of iron oxide is usually restricted to the final ripple surface or a zone only a small fraction of an inch below it, and that such zones are repeated in some cases four or five times, and that the intervening sand is poorly cemented, indicate a cementation and concentration of iron oxide contemporaneous with or immediately following the formation of the ripples. Quoting from the writer's notes made in the field, in commenting on the interpretations possible from this section, the following statements are made:

> "Zone 1. The unconformity at the top is again evidenced by a zone of poorly preserved oscillation ripple marks—trending slightly south of west.
>
> In the lower 4 feet of the sandstone the beds are very thin and contain paper thicknesses of shale every one-eighth to one-fourth inch. Most of the laminæ contain fragmented plant remains, and carbonized wood occurs in some cases. This condition gradually changes upward as the sand is cleaner and is in thin even beds.
>
> The zones of concretionary development and the hard ferruginous layers appear to be developed where a change of conditions of deposition occurred, or a short cessation of deposition, or a short exposure to conditions of consolidation, all of which may mean merely a short exposure with drying, cracking and oxidation of the surface or a zone one-fourth to three-fourths inch below the surface."

Approximately 600 feet west of the place where Section 4 was measured, zone 2 is only six feet thick and is capped in part by a zone of gnarly hard brown iron concretions, ranging from 8 to 20 inches in thickness. As the concretionary zone pinches out an irregular series of clay and siltstone takes its place.

Zones 1 and 2 probably are deposits made in a shallow gently shelving marine environment very near the shore. The ripple marks are small, having a wave length from crest to crest usually less than three inches and an amplitude of about one-fourth of an inch and being nearly symmetrical. Large ripples with a wave length of tens of feet are sometimes found in shallow water but it is doubtful if small ripples like those described here are ever formed in deep water. The small unconformity at the top of zone 2 is possibly the result of wave or littoral current erosion, or of currents of nearby streams cutting out a part of the beach or littoral deposit. The writer believes the latter to be the better explanation as the succeeding deposits of zone 3 may be such a deposit, as is indicated by the following quotation from the writer's field notes:

> "Just above the concretionary zone (at the unconformable contact with zone 2) the clay and silt is more or less sandy with a few layers of thin hard concretionary sandstone. Two feet higher is a tough gray clay with a conchoidal fracture for nearly six feet; then gradually the clay becomes sandy, until the upper three feet contains many irregular thin lenses of argillaceous sandstone and siltstone. The bedding is extremely irregular, with minute unconformities or diastems and paper thin layers of clay or shale. The conditions of deposition apparently were very irregular, with cut and fill, an occasional clay pebble as a concretion nucleus, and abrupt changes in texture. This is much as would be expected in a river deposit. Gradually these conditions give way to those of zone 4 which begins with a fine band rather evenly bedded and with thin yellow-brown layers which stand out in weathered exposures."

The dicotyledonous leaves are most abundant in the clays and silts, but fragmented leaves, stems and carbonized wood are found in all parts of zone 3.

Zones 4 and 5 are very similar to zones 1 and 2, the conditions of deposition being repeated after the accumulation of the fluviatile or deltaic deposits of zone 3. The lower part of zone 4 indicates the reworking of zone 3 as the marine waters advanced.

SECTION 5. *At Sergeant Bluff, Woodbury county, Iowa. Section 30, T. 88 N., R. 47 W., in pits of Ballou Brick Company.*

ZONE		FEET
15	*Glacial sand,* white to gray, well bedded	15
14	*Conglomerate,* pebbles of quartzite, chert, unconformable over zone 13. A Pleistocene deposit. Differing amounts of iron oxide cement	1–3
13	*Sandstone,* buff and yellow, medium- to fine-grained, friable. Many thin beds with concretionary developments and concentration of iron oxide along bedding planes. Dicotyledonous leaves common	7–8
	Mineral Analysis: Glauconite rare and partly weathered, magnetite, black tourmaline, mica, chlorite and weathered feldspars.	
12	*Sandstone,* red to buff, irregular iron oxide cementation. Where well cemented is resistant to erosion and often makes prominent ledges. Contains abundant glauconite and pyrite concretions. Where not cemented with iron oxide this zone is a typical calcitic sandstone and is similar to zone 6a of Section 1	1–2
11	*Sandstone* and *shale,* gray to brown, with some thin iron concentration bands. Grades from member below	8

Zone		Feet
10	*Sandstone,* buff to yellow, medium-grained, friable. Usually in massive beds but with occasional thin clay partings. Cross-bedding with foresets inclined NW., NE. and N. Upper part more prominently cross-bedded and shows numerous truncation planes and rippled surfaces with iron oxide as the cement. In lower 2 feet are found concretions of calcite	22
	Mineral analysis: Muscovite common; magnetite, tourmaline, feldspars, zircon, amphibole, leucoxene.	
	The sand shows many moderately well rounded and curvilinear grains in the 1- ½-mm. grade and many of them are frosted. The finer grains are angular to subangular.	
9	*Lignite,* with some coal of fair quality. Grades to carbonaceous shale at base and is overlain by a gray plastic fire clay. Lignite is 13 inches thick	1½
8	*Clay,* gray, unctuous, and with much fragmented plant material. In lower part are many small lenses of siltstone	6
7	*Siltstone,* gray, clay binder, and occasional seams of carbonized wood ..	4
6	*Shale,* dark gray to black, carbonaceous, weathers fissile. Grades downward into siltstone	6
5	*Shale, clay* and *siltstone,* buff, yellow and gray. Thin-bedded and irregularly interlaminated. Grades from zone 6 without apparent division; contains much fragmented plant material and a few leaves. Best exposed in west shale pit	20
4	*Sandstone,* yellow, brown and red, fine- to medium-grained. Concretionary, is very resistant, appears like a quartzite. Where cemented with iron oxide color has some range; where cemented with calcite is brown with glassy appearance. The concretions do not make a continuous bed. Contains fish spines and glauconite	1-2
3	*Clay,* blue-black, buff, slightly gritty, some carbonized plant remains ...	6
2	*Sandstone* and *shale,* thin-bedded and grading to siltstone in many places, coarser at base	7-8
1	*Clay,* blue to gray; tough and compact, when dry like a dense limestone and breaks with conchoidal fracture. Locally contains some grit, and lime content differs with locality. Is splotched with iron oxide. Exposed to bottom of pit	30

The entire section (other than the Pleistocene at the top) belongs to the Dakota stage, no Greenhorn occurring at this locality.

Zone 12 appears to be the equivalent of zone 6a in Section 1. The interval between zone 12 and the lignite of zone 9 is 30 feet while in Section 1 the interval is 23 to 24 feet. This may be due to an increase in thickness of the sediments deposited in the different locations, or perhaps the lignites are not exactly contemporaneous. The latter possibility may have better standing because the normal conditions appear to lack constancy.

SECTION 6. *Section 3, T. 30 N., R. 6 E., near Elk Point Ferry Landing, on Missouri river northwest of Ponca, Nebraska.*

Zone		Feet
9	*Loess,* with thin pebble zone at base	35-40
8	*Chalk,* buff to ashen gray, abundant *Inoceramus* and large fish scales and teeth. Makes a massive, prominent outcrop.	
7	*Marl,* chalky and argillaceous in thin zone and containing fossils as indicated above.	

Zone		Feet
6	*Chalk* or *marl,* blue-gray in color but more resistant than overlying zone.	
5	*Limestone* or *marl,* argillaceous, thin-bedded, with a slaty fracture. Many *Inoceramus,* Foraminifera and fish scales. Total thickness of zones 5, 6, 7, 8	38
4	Mostly covered but appears to be dark gray to black carbonaceous shale with alternating sand beds	35–40
3	*Shale,* black, very carbonaceous, fissile in part but in upper half breaks with conchoidal fracture. Contains much primary selenite and has very bitter taste. In lower 5 feet occurs a medium- to coarse-grained, evenly bedded sandstone lens ranging up to three feet in thickness	25
2	*Sandstone,* gray to buff, medium- to fine-grained, micaceous, sugary texture; contains a small pelecypod fauna like that in zones 7b and 9 of Section 1	3–4
1	*Sandstone,* fine-grained, color differing according to amount of iron oxide cement. Alternate layers consolidated or friable. Contains pyrite and iron oxide concretions, much fragmented plant material, carbonized wood and abundant glauconite. This mineral comprises approximately 15 per cent of rock. Exposed to river level. Elevation 1,125 feet	4–5
	Photomicrograph Plate IV, Fig. A.	

Zone 1 is probably the only member of the Dakota stage in this section and contains the marine invertebrates of zone 6a, Section 1. Zone 3 with its sandstone lens is more typical of the Graneros and compares with zone 14 of Section 3. As in the Aowa creek locality, Section 7, the interval between the red concretionary glauconite zone and the Graneros is smaller than in Section 1 at Sioux City. The same conditions of relative age as will be described for the Aowa creek section probably exist at this locality.

Section 7. *Section 31, T. 30 N., R. 7 E., southeast of Ponca, Dixon county, Nebraska, near mouth of Aowa creek and along Missouri river bluff.*

Zone		Feet
11	*Loess*	40
10	*Limestone,* chalky or marly, gray to buff, thin-bedded. Contains many *Inoceramus* and Foraminifera. Ripple marks with wave length 6 to 8 inches at base of this zone	18–20
9	*Limestone,* argillaceous and chalky, slate-colored, conchoidal fracture ..	12
8	*Shale* and *sandstone,* alternating with considerable calcareous and argillaceous material in upper part. Many thin zones of sandstone and shale ⅛ to ¼ inch thick. Other layers range from 2 to 10 inches in thickness in 100 feet of outcrop. Much ripple marking and cross-bedding on small scale with cut and fill and an occasional mud crack. A large amount of fragmented plant material. The shale is blue-gray and fissile, while the sand is gray, fine- to medium-grained and contains abundant glauconite, fish teeth and scales, and small pelecypod casts	20
	Thin section (07042) shows abundant glauconite, green hornblende, some brown hornblende, muscovite, weathered feldspars with the formation of a siliceous mosaic (probably a chalcedony), zircon, tourmaline, quartzite grains and calcite cement. Along seams through the section iron oxide replaces calcite in some cases with the development of rhombic pseudomorphs. The quartz grains are usually angular to subangular. Photomicrograph Plate IV, Fig. B and C.	
7	*Shale* and *sandstone.* Shale is gray-blue, carbonaceous, contains *Inoceramus,* fish remains and plant fragments. Sand in thin regularly bed-	

Zone		Feet
	ded layers with some pelecypod casts	18
	Thin section (07038) shows a rock very much like that of zone 7 above. Quartzite grains common, weathered calcic feldspars and secondary iron oxide and silica. Glauconite is abundant, occurring principally as round grains, aggregates of extremely fine crystalline units and rarely as an alteration of feldspars. The abundance of weathered feldspars with development of calcite, chalcedony and occasionally glauconite indicates an arkosic character for the original sandstone. The alteration by weathering and ground water has occurred at the site of deposition. Grains angular to subangular with approximately 15 per cent curvilinear.	
6	*Shale,* black, weathers fissile, contains selenite; nodules of pyrite and iron concretions	6
5	*Sandstone,* with tough reddish brown clay. One foot of hard red concretionary sand which contains much carbonized plant material in vertical position, and an irregular 1 to 1½-inch seam of lignite	1–1½
4	*Sandstone,* yellow, buff to brown-red, medium- to fine-grained, evenly bedded, but with occasional thin clay layer. Contains glauconite and small pyrite concretions. Near center is a thin, hard, red concretionary zone which makes a prominent ledge	18–20
	Photomicrograph, Plate IV, Fig. D.	
3	*Shale,* blue-gray, fissile and carbonaceous. One or two thin sandstone lenses	3
2	*Sandstone* and thin shale, irregularly bedded, grading downward to clay. Upper 4 feet contains concretionary zones of iron oxide. Elevation 1,120 feet. Exposed	10
1	Below water level.	

The major part of this section is younger than the Dakota stage, the base of the Graneros being located at the base of zone 6. In several respects the relations of the Dakota and Graneros are very similar to those observed in Section 3 in southern Plymouth county. Zones 5 and 4 together are probably the equivalent of zone 6a of Section 1. If this is true, the overlying Graneros of Section 7, Aowa creek, is relatively older than the Graneros of Sections 1, 2, 3 and 5.

For a distance of one to two miles northwest of Homer along the road to Hubbard and Jackson are several small exposures of Dakota sandstone. In these disconnected outcrops there appears to be a continuous zone of sandstone which makes a more or less massive outcrop in the bluff. At a point one and one-half miles northwest of Homer the following section was measured:

Section 8. *Section 2, T. 27 N., R. 8 E., northwest of Homer, Dakota county, Nebraska, near bluff road.*

Sandstone, buff to brown, medium-grained, friable, with few small iron concretionary nodules. Cross-bedding common in zones ranging from two or three inches up to one and one-half feet. Foresets inclined principally to N., NE. and NW., though some are seen to be inclined to SE. Truncations horizontal and inclined in northerly directions. Elevation at base of section approximately 1,120 feet. Exposed 16 to 18 feet.
Photomicrograph, Plate IV, Fig. F.

Above the section described the slope is covered for approximately 180 feet to the top of the hill, but an occasional small protruding ledge indicates the presence of thin hard concretionary sandstone layers up to 60 feet above the exposure. These beds are overlain by a chalky limestone containing *Inoceramus* shells. A fresh water spring issues from the lower part of the sandstone described above, so it is probable that the medium-grained sandstone is underlain by a siltstone, a clay, or alternating shales and sandstones.

Section 8 is one of the exposures of sandstone nearest to Dakota City and occupies a position in the bluffs such as described by Meek and Hayden.[140] Unless the exposures were much better at the time Meek and Hayden visited the area it is doubtful if they obtained conclusive evidence from this section.

Continuing southeastward along the northeast facing bluffs which border the alluvial plain of Missouri river are several small exposures similar to Section 8.

In the bluff two and one-half miles southeast of Homer, Section 20, T. 27 N., R. 9 E., Dakota county, another small exposure was observed.

SECTION 9

Sandstone, buff to yellow-gray, fine- to medium-grained. Appears as a massive bed but on weathering shows many thin cross-bedded zones. Foresets inclined to east and southeast in zones up to two feet thick. Truncation planes horizontal and inclined to southwest and northeast and marked by many small concretions. Cementing material chiefly calcite but with some iron oxide. This outcrop and adjacent ones have been described by previous workers as having the characteristics of a quartzite. Thickness exposed 25 feet.
Photomicrograph, Plate IV, Fig. E. Iron oxide cemented portion.

The most complete and typical exposure of the Dakota rocks in northeastern Nebraska in the type area is found about one and three-fourths miles south of Homer, Dakota county. This section is over five miles from Missouri river and almost two miles from the bluff line at Homer, so it is doubtful if Meek and Hayden or other early workers observed it. No mention of this locality is made by Gould,[141] Condra[142] or Burchard[143] in their detailed discussions of the stratigraphy of Dakota county and adjacent areas.

The upper part of the section is exposed in a road cut on U. S. Highway No. 77 about three-fourths of a mile southwest of the principal part of the section. The most complete part of the section

140 Meek, U, S. G. S. Terr., Vol. 9, p. XXV, 1876.
141 Gould, Kans. Acad. Sci. Trans., Vol. 17, p. 137, 1900.
142 Condra, U. S. Geol. Surv. W. S. Paper 215, pp. 8-11, 1908.
143 Burchard, Acad. Sci. and Lett. Sioux City, Proc., Vol. 1, pp. 147-149, 1903-4.

is found immediately above a steep cut bank at a sharp bend in Omaha creek. The extremely abrupt changes of the rocks of the Dakota stage make it highly desirable to find a single section with as much of the sequence as possible. Correlations of zones and members where only a few feet are exposed is extremely difficult and the results are questionable.

SECTION 10. *SW. ¼ Sec. 23, T. 27 N., R. 8 E., and NE. ¼ Sec. 26, T. 27 N., R. 8 E., about 2 miles south of Homer, Dakota county, Nebraska. Elevation Omaha creek at base of section approximately 1,115-1,120 feet.*

ZONE		FEET
9	*Sandstone,* red, brown, fine-grained, micaceous, iron oxide and clay cement, in thin beds, with concretionary development. Principal grades between one-fourth and one-sixteenth mm. Larger grains curvilinear to subround. Minute cross-bedding seen in well compacted zones. Presence of glauconite uncertain. Best observed in section 26 east side of Omaha creek. Exposed	1–2
8	*Sandstone,* gray to buff, friable, fine-grained, evenly sorted, micaceous. Lower half more or less massive bed, upper half in several thin beds with differing cementation. Lower part with foresets of cross-bedding inclined N. and NW.	6–7
7	*Shale* and *sandstone,* alternating in thin beds. Sands are buff, fine-grained, ranging to siltstone, micaceous; shales are gray, plastic and micaceous, in some places grading to silt. Entire zone contains much fragmented plant material. Exposed	10–12
6	*Sandstone,* buff to yellow, friable, well sorted, medium-grained, uniformly cemented by iron oxide, micaceous. Grades upward to less friable and firmly cemented ferruginous and calcitic rock sometimes called "quartzite." Top 4 to 5 feet contains much gray clay in thin seams, nodules and as pebbles. Middle and upper middle parts show small oscillation ripples with crests trending NW.-SE. Lower part cross-bedded with foresets inclined W. and SW. The zone 10 to 14 feet from base contains much fragmented leaf material and an occasional good specimen	18–20
	Minerals: Glauconite (?), zircon, tourmaline, green hornblende, leucoxene, basic feldspars, quartzite and chert. Many grains show excellent rounding on several surfaces, with deep pitting and frosting. This type, however, is not conclusive of wind abrasion.	
5	*Sandstone* and *shale,* alternating, with single beds ranging from a fraction of an inch to over three feet in thickness. Impractical to subdivide this zone as individual layers change in composition within a few feet laterally. Sandstone is white to gray, fine-grained and of wide range in cementation. Many of the sand beds are capped by a hard iron oxide concentration, especially where ripple marks are preserved. Cross-bedding in middle part on large scale, foresets inclined to S., SW. and SE. Clay is gray-drab, carbonaceous and occasionally quite sandy, and with many thin limonitic concretionary zones. There is a definite interfingering of sand and clay. A channel cut in the thin alternating layers of sand and clay near the base is filled with sand containing lenses of clay, but unconformable with the sides of the channel cut by currents. This channel probably was cut by the current of the stream depositing the sands and clays. The contact with zone 4 is unconformable	25–38
4	*Sandstone,* white to gray, fine-grained, micaceous, small cross-bedding to S., SW. and SE. Top of member has a concretionary zone at the unconformity with overlying zone 5	4–5

Zone		Feet
3	*Sandstone,* gray to white, medium- to fine-grained, friable, micaceous, grains subangular to subround and many curvilinear; many well frosted. Massive beds. Some small cross bedding. Contact with zone 2 irregular	4–5
	Photomicrograph Plate IV, Fig. H.	
2	*Sandstone,* gray to yellow and buff, medium- to fine-grained, friable, micaceous. In single massive bed. Very little different from zone 3 except for greater amount of iron oxide as cement	3–4
1	*Sandstone,* like zone 2, but separated by a wavy irregular line of iron concretions and a few small clay balls. Cross-bedding prominent, foresets inclined to S. and SW. Exposed to creek level	3½
	Photomicrographs Plate IV, Fig. I and J.	

Zones 1, 2, 3 and 4 are almost identical in several respects. The large amount of wear and frosting on the grains, the absence or small amount of iron oxide as cement and the similarity in size grade distribution and the scarcity of accessory minerals indicate that these zones might be considered as a single member. The general regularity of bedding, and, where cross-bedding occurs, the common direction of foresets indicates a condition of deposition with little variation. Such a condition could be accomplished in water of only moderate depth, or in an estuary some distance from the mouth of the stream. The currents which supplied the medium- and fine-grained sand at the same time sorted the material and deposited it with minor foreset zones. The writer believes the sand came from a nearby beach where wave action had been efficient in sorting and abrading the grains. The direction of inclination of the foresets indicates a general south of southwest course of the currents with the source toward the north and northeast.

Zone 5 apparently was deposited in a broad, shallow estuary, or is part of a delta built by a stream rapidly aggrading and with a meandering course. Cut and fill is common in this zone and the rapid change in thickness and composition of many of the units indicates a shifting current. The stream advanced its delta southward, overlapping the estuarine or littoral deposits of the lower zones.

The sands of zone 6 probably were deposited in a slowly encroaching sea which covered the deltaic deposits of zone 5. The presence of oscillation ripple marks and the uniform cross-bedding indicate the shallow ocean environment. Conditions changed back and forth; it is doubtful if one could draw the exact boundaries separating the deposits made directly by a stream emptying into a bay or gulf from the sands reworked and deposited by waves or littoral currents. In either case well sorted sands could be deposited evenly or in uniform lenses, or muds could be included as thin irregular lenses or as interlaminations with the sands. It is an environment where one set of conditions characteristic of a gulf or bay may control for a period of time and then be displaced by a new set which is dominated by the stream factors.

Zones 7, 8 and 9 add very little to the general conclusions above. In zone 8 the direction of inclination of foresets is different from that noted in the lower members, but this may be the result of shifts in the position of one of the mouths of the stream building the delta, or a change in detail of the course of a littoral current.

Of some significance is the absence of undoubted glauconite in the sandstones of this section. The writer has no explanation to offer. In all other sections in the type area one or more members of the Dakota stage contain some glauconite.

South of Dakota county, Nebraska, along the Missouri River bluffs in Thurston and Burt counties, more or less continuous evidence of the Dakota stage may be observed. The exposures near Tekamah, about thirty miles south of Sioux City, mark the southern limit of the rocks which appear to belong in the same class as the type area Dakota. The sandstones are variable in color, depending on the amount of iron oxide present and the degree of oxidation or hydration. Concretions are common. The rocks are fine-grained, with bedding which is uneven and cross-laminated, with foresets inclined most commonly to the south, southwest and southeast.

An exposure observed eleven miles north of Tekamah in a farm lot on the west side of Nebraska state highway No. 51 shows several feet of irregularly bedded coarse-grained conglomeratic and ferruginous sandstone. The foresets of the cross laminations are inclined to the southerly quadrants. At the top are gnarly concretions and mixtures of thin clay lenses. At the base of the conglomerate is a more regularly bedded fine-grained gray and yellow sandstone with southeast and southwest inclined foresets. The six feet of this sandstone exposed is very similar to the lower four zones of Section 10, just south of Homer.

About eight miles west of Decatur, Burt county, on Elm creek, near the Lyons-Decatur highway bridge, is an isolated exposure of considerable significance.

Elm creek has cut through the sandstones and shales of the Dakota stage for a distance of about one-half mile. There is a heavy mantle of drift and loess which extends below the creek level on both sides of the Dakota exposure. The Dakota apparently was a topographic high in preglacial time.

In detail the section is as follows:

SECTION 11

Zone		Feet
B.	The younger sediments which fill the channel. *Shale,* clayey. Near unconformity is blue-black but grades outward to a gray, buff and mottled color; at the unconformity the bedding is poor but toward the south it is thinly laminated, with sandstone zones interbedded, showing concretionary development and ripple marks. The upper clays and silts contain some good leaf impressions and much fragmental plant material	8–15
A.	The older part of the exposure. *Sandstone,* buff, yellow, medium- to fine-grained. Usually the sorting is very good in individual beds; micaceous, and friable. In the lower 6 to 8 feet the sands are intricately cross-bedded with foresets inclined in every quadrant, but with NE. and NW. directions predominating. The truncation surfaces are in many cases ripple marked, most of these marks being of the symmetrical type. Dicotyledonous leaves are found in the upper middle fine-grained beds. Toward the top the beds are silty and shaly and more thinly bedded. Sample from a lower zone contains a small amount of glauconite	22–26

The section of the Dakota shows two types of rock; one a series of fine-grained micaceous sands, with highly cross-bedded and rippled zones, and the other, clayey shales and silts with thin layers of sand. These rocks are separated by an unconformity which cuts across the exposure from top to bottom. The writer interprets this condition to be one of a channel cut in a littoral bar and then filled with clay and silts as the stream current was able to deposit materials in its bed. Only one side of the old channel is well exposed in the valley wall of Elm creek, but upstream several hundred feet the fine-grained cross-bedded sandstone is exposed again, indicating the other bank of the channel. The present exposure in the creek is at an angle with the old channel so that a direct measurement between banks is not the true cross section width of the channel. The channel was probably about 300 feet wide at this point.

There is no question in the writer's mind concerning the unconformable relationships of this section. The sandstone beds of A in the above description are distinctly bevelled and do not grade or interfinger into B. The curvature of the plane of separation and the concentration of iron oxide along this plane and the character of beds of zone B, all preclude the possibility of a fault. The commonness of such a condition of cut and fill in the Dakota rocks also argues for this conclusion.

Many other small outcrops, showing only a few feet of sandstone, or interbedded sandstones and shales, were visited in Dakota, Dixon, Thurston and Burt counties, Nebraska. None of these exposures adds to the detailed knowledge of the Dakota stage, as very little new information may be derived from them. It is true these sections help one to follow the formations in the field and to understand better the general distribution of the different zones, but it is also true that a single zone often changes character abruptly, and two sections at the same level only a few hundred feet apart, but concealed in the interval, will show distinctly different types of rock.

CHAPTER VI

THE DAKOTA ROCKS OF ADJACENT AREAS

No attempt is made to give a complete discussion of all the exposures of rocks called Dakota in western Iowa, southern Nebraska, northern and central Kansas, or elsewhere. The writer has studied in the field practically all of the exposures in the areas named and can make comparisons and correlations with the rocks in the type area.

In southwestern Iowa, particularly in Cass, Montgomery, Page and Guthrie counties, there are numerous exposures of rocks which the writer believes are equivalent to parts of the Dakota stage of the type area. These rocks have been correlated generally with the Dakota because of their lithologic characteristics and the local abundance of dicotyledonous leaves, which are very similar to those reported by Bartsch[144] for western Iowa. The writer has not made a detailed study of these leaves.

Continued field work on the Dakota rocks in southwestern Iowa has failed to locate a horizon containing a marine or brackish water invertebrate fauna. In fact, the only locality that is known to the writer to have yielded invertebrates is at Sioux City and nearby sections, as previously described.

The usual exposures of rocks correlated with the Dakota are small, and the beds can be traced laterally only a few thousand feet or fractions of a mile. The overburden of glacial drift is normally rather thick, and the possible lenslike nature of the Dakota sandstone makes it difficult to find continuous outcrops.

A section of the Dakota one mile southwest of Lewis, Cass county, Iowa, may be taken as characteristic for the west-central Iowa region.

SECTION 12

ZONE		FEET
6	*Sandstone,* white to buff and yellow, fine- to coarse-grained, friable. Appears to grade upward to finer sands; a layer of gray thinly laminated clay appears 18 to 20 feet from base but is not continuous. There are many very local and irregularly exposed clay conglomerate zones with boulders of clay up to 10 and 11 inches in diameter and 3 to 4 inches thick. These zones, though occurring at irregular horizons, are discontinuous and are nearly horizontal on wavy surfaces. The pebbles and boulders of clay have their longer axes parallel, or nearly so, to the surfaces on which they rest. The differences in amount of iron oxide cement give	

144 Bartsch, Bull. Lab. of Nat. Hist. S. U. I., Vol. 3, No. 4, pp. 178-180, 1896.

Zone		Feet
	the sandstone a locally banded appearance. About 21 feet from the base of this zone a gray shale bed increases in thickness toward the east and southeast. Eastward the base of the shale zone contains a hard, red, finely sandy concretionary zone	28–32
5	*Shale,* green to gray, thinly laminated and resting on a wavy, hummocky surface, which is brown to red, owing to concentration of iron oxide. Much of the shale occurs as conglomerate pebbles. The zone is irregular and probably not continuous for a great distance. Average thickness	½
4	*Sandstone,* yellow to buff and white, friable, coarse-grained. Contains many irregular zones of poorly developed iron oxide concretions and clay conglomerate pebbles. Cross-bedding inclined to south-southeast ..	6½
3	*Sandstone,* generally covered except for very small exposures, where it appears to be similar to that above	7
2	*Sandstone,* and conglomerate shale, with much iron oxide and interfingering of thin lenses. Very poorly exposed	3
1	*Limestone,* upper Pennsylvanian. Exposed, approximately	4

About one-fourth mile northeast of the exposure described in the previous paragraphs there is a good outcrop of the hard red ferruginous medium- to coarse-grained sandstone that is so characteristic of the Dakota of central and northern Kansas. The few ledges show excellent cross-bedding with foresets inclined to the south-southwest and west at an angle of about 15 degrees. The elevation of this exposure is about the same as the top of zone 6 in the previous section.

In southern Montgomery county, Iowa, along the bluffs of the east branch of Nishnabotna river, and particularly south of Red Oak and adjacent to Coburg, are several exposures typical of Dakota sandstone

FIG. 27.—A series of regular foresets seen in zone 5 of Section 13, at Coburg, Montgomery county, Iowa.

and conglomerate. A section measured just east of Coburg, in the south half of section 30, T. 71 N., R. 38 W., has the following characteristics.

SECTION 13

Zone		Feet
6	*Silt to clay,* gray to buff, contains much fragmented plant material and carbonized wood. Exposed	8–10
5	*Sandstone and conglomerate,* dark brown, red and yellow. Very irregularly bedded with particles ranging from sand to cobble grades; cement very unevenly distributed with some concentrations as concretions surrounding yellow friable masses. The pebble zones are irregularly distributed, though in detail they appear to be concentrated as foreset beds or small depression fills. The pebbles and cobbles are principally a brown chert and gray vein quartz. The cross-bedding is normally constant for single zones, but the variety includes inclinations of foresets to the southwest, west and south. Figure 27 shows one of the upper hard ferruginous cross-bedded zones of the coarse sand and peanut gravel. Zone 5 overlies Zone 4 unconformably	12–25
4	*Sandstone,* yellow, buff and gray; wide variety of sizes of grains, ranging from cobbles to medium-grained sands. Cementation differs, controlling color and friability of rock; not generally as well cemented as Zone 5. Color bands follow cross-lamination directions. Throughout exposure practically every possible direction of cross-bedding may be noted; in the upper part the directions of foresets are dominantly in the north-northwest quadrant; in the central and lower parts the foresets range from southwest, south, southeast, to east. In several zones there are definite 2-to 3- inch bands of pebbles which are usually nearly horizontal or inclined at very low angles; the less sand contained in the pebble zone the more horizontal is the position. Figures 29 and 30 show two views of the pebble bands and cross-bedded zones of this part of the exposure	12–15
3	*Conglomerate,* pebbles up to three-fourths inch in diameter. Makes a definite band in nearly horizontal position	2–3

FIG. 28.—The upper ferruginous sandstone and the friable yellow irregularly bedded and conglomeratic sand at Coburg, Montgomery county, Iowa.

FIG. 29.—Detailed view of yellow, friable sandstone with conglomerate zones. Note the relation of the foresets and pebble band on the horizontal truncation planes.

ZONE		FEET
2	*Sandstone,* medium- to coarse-grained at base grading to finer sands at top. Foresets inclined to south-southwest. At base is a single layer of pebbles lying on irregular contact of Zone 1	1–2
1	*Sandstone,* yellow to buff, medium- to coarse-grained with conglomerate in some of the foreset zones. Cross-bedding inclined to the north-northwest-west. Exposed	2–3

In the northwest part of section 17, T. 71 N., R. 38 W., Montgomery county, north of Coburg, Iowa, there is another good exposure which shows a conglomerate and peanut gravel similar to that just described in the locality east of Coburg. Lonsdale[145] has described this material as puddingstone. The upper part of the rock is not well exposed, and there are only 20 feet contained in the fresh exposure.

[145] Lonsdale, E. H., Iowa Geol. Survey, Vol. IV, pp. 381-451, 1895.

FIG. 30.—A detail of part of the section below Figure 29. Note the reverse directions of fore-sets in the zone below the knife.

This shows a pebble to cobble conglomerate with a matrix of coarse sand, clay balls, and considerable iron oxide cement. The rock is much more tightly cemented and is of a darker brown and red color than that seen at Coburg. A very fresh exposure shows a lighter brown color. In general the cobbles are coarser from the base upward; below the puddingstone conglomerate there is a gradation to a medium fine-grained yellow, buff micaceous sandstone.

The cross-bedding of the puddingstone differs but is predominantly to the south-southwest with an inclination of 18 degrees. In the lower fine-grained sand the cross-bedding is also mainly to the south-southwest but with some thin zones consistently to the southeast.

The writer knows of no other locality in southern Iowa where as thick a section of coarse material of Dakota age occurs. However, west and north of this locality, approximately 45 to 50 miles and just east of Louisville, Nebraska, there is a similar exposure. As these two exposures have a great deal in common, including the composition of the pebbles, the texture and the bedding, it is quite possible that at one time they were a part of a series of lenses which extended from east to west and bordered the old shore line.

In southern Nebraska, near Fairbury, Beatrice, Hastings and Endicott, are found exposures of fine-grained and buff to yellowish sandstones which in some cases contain dicotyledonous leaves.

An exposure along the Chicago, Burlington and Quincy railroad on the south bank of Platte river, about two and one-half miles southeast of Ashland, Nebraska, shows the Dakota sandstone resting directly on the Upper Pennsylvanian limestone. The lower part of the sandstone is a coarse-grained brown poorly cemented type, with foresets inclined 20 to 22 degrees to the west and northwest. The series continues with little change except for local alterations in exact direction of cross-bedding and minor differences in texture. About 20 to 25 feet above the base the grain becomes very coarse and pebbly with foresets often showing in the coarse-grained zones. About 30 feet above the limestone the cross-bedding is more intricate, there is a greater range in thickness of zones, and changes in the grade of the sand are more abrupt. This zone is 12 to 14 feet thick. The upper six to seven feet of sandstone is coarse-grained and almost a conglomerate. Above this the section is poorly exposed and covered by drift and loess from above. The total exposure is about 50 feet thick.

An excellent section is exposed on the main line of the Chicago, Burlington and Quincy Railroad near mile post 112, east of Endicott, Nebraska. The exposure in the cut shows about 15 feet of soft gray and yellowish fine-grained sandstone which in places grades locally into clay or a very argillaceous sand. The upper half of the exposure is marked by thin limonite-colored hard sandy lenses which are very irregular in their extent and range from horizontal to steeply inclined positions. The limonite-colored zones mark a cementation process which took place probably soon after the deposition of the sandstone. Along some of the thicker zones of cementation hard and gnarly concretions are developed.

A large lens of nearly pure sand, with very little clay but with considerable iron oxide cement, occurs at one place. The lens departs directly from the argillaceous sandstone which comprises most of the rocks in the cut. This condition is evident on both sides of the track. On the east side of the cut the sand interfingers with the argillaceous material. The inclination of the foreset beds of this sandstone is dominantly to the south, with some inclined to the southeast and southwest. A few zones of the foresets are 8 to 10 feet long and are inclined at an angle close to 22 degrees.

The irregularity of some of the cross-bedded zones, the variety of truncations, the interfingering of clay and sandstone lenses, the local cuts and fills, all indicate the variety and rapid changes in the conditions of deposition of the materials in the Endicott section.

At several localities northwest of Fairbury, Nebraska, the Dakota rocks may be observed. Along the St. Joseph & Grand Island railroad at mile post 157½, approximately five miles northwest of Fairbury, the exposures show 20 to 25 feet of gray and brown clay with thin sandstone zones, overlain by three to five feet of massive bedded medium- to coarse-grained light colored sandstone. This in turn is overlain by 20 to 35 feet of gray clays which are mottled gray and red with many thin sandstone lenses. Unconformably overlying the last mentioned clay is a hard fine-grained calcareous sandstone. This sandstone appears to be more or less concretionary and occasionally weathers in dark red to brown blocks. It is very similar to the calcitic, concretionary sandstone of zone 6a, Section 1, Sioux City, Iowa.

In section 19, T. 3 N., R. 2 E., northwest of Fairbury, Nebraska, is a section of Dakota clays and shaly sands immediately overlain by the Graneros member of the Colorado stage. The section observed at several points in the southwest corner of section 18 and the adjacent part of section 19 is given below.

Section 14

Zone		Feet
8	*Limestone and shale,* apparently grading from below. Abundant *Inoceramus.*	
7	*Shale and clay,* gray and brown, containing many sandstone lenses one-fourth to one-eighth inch thick. Upward the zone is brown and shows an increase of sandstone	35
6	*Shale,* black to gray, carbonaceous, fissile, with considerable concretionary material. Grades upward to brown thin sandy shale	5–8
5	*Calcite cone-in-cone,* irregular in distribution. One 2-inch layer with 3 inches of impure limestone at top. The 3 feet of exposure is capped by a hard iron oxide concretionary layer	3

ZONE		FEET
4	*Clay* and *shale,* some dark gray to black, carbonaceous, and some parts fissile. An occasional thin sand lens	3
3	*Lignite,* impure, soft and earthy, grades into a highly carbonaceous shale	⅓
2	*Clay,* gray, unctuous, poorly exposed	8–10
1	*Sandstone,* yellow, concretionary and friable, with alternating gray clays and siltstones. Irregularly exposed in creek bank. Approximately	40

In the sections described above there are two features which appear to be of some importance when one is attempting to correlate the conditions of deposition with those of the formations in northeastern Nebraska, adjacent to the type locality. The occurrence of the gray interfingering silts and clays below the fine yellowish sands which underly the lignite is very typical of the Sioux City section. The occurrence of cone-in-cone is suggestive of the Comanchean formations of central Kansas. It will be noted in the sections described above that sandstone is relatively rare, and in particular as thick massive beds. The gradation at the top into the Graneros formation (zone 7) which in turn grades to the Greenhorn formation (zone 8) of the Colorado stage makes it difficult to draw any distinct line of separation between these various formations.

Section 14 and the exposures along the St. Joseph & Grand Island railroad northwest of Fairbury are in the locality described by Hicks[146] as yielding a fauna of marine invertebrates and later described by White[147] as carrying a fresh water fauna. The writer was unable to find any fossils in this locality.

In sections 11 and 12, T. 2 S., R. 3 E., Washington county, Kansas, just south of the Spring creek bridge about five miles north of the town of Washington, may be seen a section of yellow, brown friable and medium-grained sandstone. The cross-bedding in this sand has a wide range, foresets being observed with inclinations to the north, northwest, west and southwest. Near the top of the cut bank, the highly cross-bedded zone is overlain unconformably by an irregular zone of interfingering sandstones and argillaceous shales. At the base of this upper zone the grain is very coarse, with an occasional pebble of quartz or flint and many small clay balls and concretionary siltstones. The cross-lamination of the upper sandstone is predominantly inclined to the west-southwest, the foresets having an angle about 12 to 15 degrees and being 20 to 25 feet long. To the east of this exposure

146 Hicks, L. E., Amer. Assoc. Adv. Sci. Proceedings, Vol. 34, pp. 217-219, 1885.
147 White, C. A., U. S. Natl. Museum Proc., Vol. 17, pp. 131-138, 1894.

and up the hill there is very little rock exposed, but talus blocks of dark red coarse-grained concretionary cross-bedded sandstone may be seen.

Another section in Washington county, Kansas, in the northwest part of section 32, T. 2 S., R. 4 E., along Mill creek, shows the wide range in the nature and relationships of the Dakota section. A generalized description follows:

SECTION 15

ZONE		FEET
6	*Float,* much like Zone 5, and typical of the coarse-grained ferruginous Dakota sandstone.	
5	*Sandstone,* dark brown, red to black, hard and well cemented by iron oxide; texture irregular, ranges from medium- to coarse-grained and almost conglomeratic. Cross-bedding with foreset zones up to 2 feet thick and 4 to 6 feet long; inclination to west-southwest and some to northwest; the larger and more persistent are inclined at an angle of 15 to 18 degrees. The contact with the underlying zone appears to be unconformable, but the actual relationships may be the result of cut and fill due to shifting of currents	24–28
4	*Sandstone,* gray to brown, calcitic, with small amount of iron oxide, similar to the rock sometimes described as a quartzite. Lower part intricately cross-bedded on a very small scale, zones of foresetting 10 to 14 inches thick, foresets inclined 10 to 12 degrees in south, southwest and west quadrants. Upward the sand is poorly cemented and changes color to a yellowish brown. The lower 5 feet of the friable zone is evenly bedded, while the upper 10 to 15 feet repeats the intricate cross-bedding seen in the lower part but with long gently sloping foresets with southwest, west, northwest inclinations. The well cemented "quartzitic" type of rock may be a local phase, but it is a characteristic feature of the rocks of this region. The similarities with the calcitic sandstone of the type area near Sioux City are close	30–33
3	*Shale,* brown and gray, calcareous. Permian	33
2 & 1	Permian *limestone* and *shale*	35

In the southeast quarter of section 32, near the rocks described above, gray and brown clay and shale series with the red hematitic sandstone lenses is very well developed. The shales continue to the crest of a prominent ridge, which is 75 to 80 feet higher than the base of the sandstone of Section 15. The position of these rocks cannot be accounted for by dip and it appears that the ridge was probably a topographic high at the time of the deposition of the coarse-grained highly cross-bedded ferruginous sandstone of zone 5 of the section just described. The contact with the Permian rocks is also one of distinct unconformity, as may be seen about one and a half miles north of the section just described. At this place a "butte" of Permian calcareous shales and thin limestones stands 30 to 35 feet above the base of the irregularly cross-bedded yellow friable sandstone of Dakota age.

The irregular relationships of the characteristic medium- to coarse-grained ferruginous sandstone horizon are seen in many localities in Washington county. Along the Washington-Clay county line in sections 33, 34 and 35, T. 5 S., R. 2 E., and sections 3 and 4, T. 6 S., R. 2 E., is a very instructive section.

In the highway cut at the south side of section 35 only clay and soft yellow sandstone are exposed, overlying a red mottled gray clay. This section continues down to the creek level about 30 to 35 feet lower. At a large cut across the north center of section 3, T. 6 S., R. 2 E., the exposure at the same level is entirely of a soft, gray-yellow sandstone with very thin alternating beds of clayey shale and argillaceous sandstone. About 25 feet below the top of the cut is a hard gray-brown to red sandstone with some conglomeratic grains of quartz and bearing dicotyledonous leaf material. On the opposite side of a small draw about one-quarter mile west this leaf-bearing sandstone is much thicker and continues to a level 50 to 60 feet lower. It is apparent that the coarse-grained ferruginous sandstone increases in thickness from about 8 feet on the east side of the draw to approximately 70 feet within one-fourth of a mile to the west. This probably is an old channel fill, the coarse-grained sands being the alluvial and bar deposits. In section 3, as previously indicated, the leaf-bearing sand is overlain by soft gray and yellow sandstone. At the top of the hill there is much float of a hard ferruginous concretionary sandstone similar to that just described as the stream fill. It appears then that the ferruginous concretionary sandstone may be repeated at more than one elevation and is not a distinctive stratigraphic unit; the conditions responsible for such stream deposition alternated with conditions which deposited finer grains and silty sediment.

The writer has observed and measured sections in a large number of localities in Clay, Cloud, Ottawa, Mitchell, Lincoln, Russell, Ellsworth, Saline, McPherson and Rice counties of central and north-central Kansas. These sections show without much question the irregular characteristics of the Dakota rocks. There are shales, siltstones and fine- to medium-grained sandstones in thin alternating beds, normally poorly consolidated and without continuity over a large area; and there are hard concretionary ferruginous sandstones which thicken and thin, have a wide range in grain, and have more or less persistent cross-lamination; these in some cases are unconformable with the alternating shales and sands first mentioned. It is believed that the coarse-grained cross-bedded ferruginous sandstone was deposited as a channel fill by streams which extended their courses over the deltaic and adjacent shallow water deposits represented in the lower section.

In northern and central Kansas the conditions described above occur rather commonly. Many of the ferruginous coarse-grained channel-fill sandstones carry a dicotyledonous leaf flora, and the writer has collected invertebrates from beds immediately overlying this type of rock. The lower sands and shales also contain some dicotyledonous leaves, and certain zones locally are filled with fragmented plant remains and occasionally are lignitic. The relationship of the leaves in the lower zone to those in the stream channel deposits is not certain to the writer. However, he made a collection of leaves from the gray and iron-stained clays of section 3, T. 16 S., R. 9 W., southwest of Ellsworth, Ellsworth county, Kansas, and these were identified by Dr. E. W. Berry of Johns Hopkins University in 1925. The determinations by Berry are listed below.

Andromeda parlatorii Heer
Andromeda pfaffiana Heer
Dammara borealis Heer
Eucalyptus Dakotensis Lesquereux
Liriodendropsis simplex Newberry
Myrica longa Heer (?)
Myrsine gaudini Lesquereux
Protophyllum sp.
Protophyllocladus subintegrifolius Lesquereux
Rhamnites apiculatus Lesquereux (?)
Sassafras acutilobum Lesquereux (?)
Widdringtonites reichii (Ettingshausen)

Berry comments on these forms, saying "most of the forms have been recorded from the Dakota but a couple have not, and none occur in the Cheyenne sandstone of Kansas. In the Atlantic Coastal Plain the majority are found in beds which I regard as of Turonian age, so there can be no question but that this horizon in Kansas is Upper Cretaceous."[148] The argillaceous material in which the leaves described above are found lies beneath the stream-deposited red ferruginous coarse-grained sandstone but may not be decidedly older than the red sandstones in other localities.

From another locality, in the southeast quarter of section 10, T. 16 S., R. 5 W., Saline county, Kansas, the writer made a small collection of leaves from a cross-bedded coarse-grained ferruginous concretionary sandstone which occupies a position unconformably over

[148] Berry, E. W., personal communication, dated Feb. 26, 1925.

the Comanchean. The relationship appears to be similar to that previously described; that is, the clays and sandstones were cut out and the channels filled with the coarse ferruginous sand. In this particular locality, however, there is no question concerning the age of the lower series, as the presence of the Mentor fauna classifies it as being of Comanchean age. Berry identifies the following forms from the upper sandstone:

Araliopsoides cretacea (Newberry)
Cones, probably Alnus
Dammarites cf. emarginatus (Lesquereux)
Sassafras cretaceum (Newberry)
Sassafras (Araliopsis) mirabile (Lesquereux)

The material from this locality is unquestionably a Dakota flora,[149] which, as defined by Berry, is related to the Woodbine flora of Texas.

Stanton[150] considers the fossils which he found near Denmark, Lincoln county, Kansas, as showing closer relationship to the upper Dakota fauna of Nebraska than to the Mentor faunas of Kansas. He does not describe the beds from which he collected these fossils and as the writer was not able to duplicate his collection it is uncertain in just what horizon they occur. Rubey and Bass[151] state, however, that the fossils collected by Stanton in Mitchell and Lincoln counties were found in the beds near the top of the Rocktown member. However, the fact remains that a fauna with Dakota affinities occurs in northern Kansas and that the uppermost beds of the Dakota stage are closely related to the underlying formations, which contain a dicotyledonous flora which Berry believes to be a characteristic Dakota flora. At the same time it must be remembered that the well-cemented coarse-grained sand which occurs in so many localities in northern Kansas generally appears as alluvial deposits filling old valleys and spreading over the previous divides. This condition may indicate an extensive emergence of the lower clays, cross-bedded sandstones and calcareous rocks, followed by a general expansion of rivers of the Platte type over the region of low relief.

Rubey and Bass[152] explain the upper 125 feet of the Dakota sandstone of Russell county, Kansas, as being a broad stream channel deposit. They give the name "Rocktown Channel Sandstone Member" to this part of the Dakota stage. They also call attention to the inter-

149 Berry, E. W., personal communication, Feb. 26, 1925.
150 Stanton, T. W., Geol. Soc. Amer. Bull., Vol. 23, pp. 255-273, 1922.
151 Rubey, W. W., and Bass, N. W., Kans. Geol. Surv., Bull. 10, p. 63, 1925.
152 Op. cit., pp. 57-63.

lamination and interfingering of the gray and mottled reddish clay deposits with the coarser-grained highly cross-bedded Rocktown member. This feature is characteristic of the sandstone as observed by the writer, and at the same time he believes that the coarse sandstone interfingers or lenses with other clay beds. Even if the upper part of the Dakota sand is a distinct channel fill the relationship with the underlying formations is very close. The time interval between the emergence of the lower clays and sands and the deposition of the channel sandstone is very short. It is even probable that some parts of the lenses of sandstone which appear as channel deposits but which interfinger with the adjacent clays were deposited in the littoral zone as bars or as fillings in current channels bordering the beach. The normal condition as seen in the outcrop is a channel or depression which was cut in the clays and alternating siltstones and sandstones, filled with the coarser sand to near the top of the channel, and then covered by coarser cross-bedded sands which were spread across the upper surface of the clays. The writer would expect a bar deposit, either littoral or stream channel, to have some relief above the clays or finer contemporaneous deposits and the interfingering beds to slope away from the coarser-grained bar. The lows adjacent to the bars may be filled with fine materials during the closing stages of the bar deposition. A channel fill does not have the relief of the bar and, as indicated, is a deposit made in a depression or eroded channel that is lower than the adjacent deposits and undoubtedly is lower than some contemporaneous deposits made in other parts of the stream channel. In the majority of cases in which the writer has observed the type of deposit described as a channel fill, the slope of the beds was toward the center of the fill and this inclination decreased toward the top as the beds spread laterally.

One of the best examples of a deep erosional channel which was filled by sandstones of the Dakota stage may be seen at the picnic ground called "The Rocks", in sections 13 and 14, T. 19 S., R. 7 W., west of Little River, Rice county, Kansas. The Comanchean series containing the fossiliferous Windom member, cone-in-cone shale zones, and the Mentor horizon is channeled to a depth of 45 feet and a width of about 1000 feet. In the channel is a deposit of friable, micaceous, medium- to coarse-grained sandstone. The upper 18 to 20 feet is prominently cross-bedded with foresets inclined to the southwest, west and northwest. Many of the truncation planes are marked by thin zones of concretions and nodular pebbly materials with clay centers.

One-fourth of a mile west of "The Rocks" a medium-grained light brown to red sandstone shows the continuation of the channel fill. The foresets in the exposures here show inclinations ranging from 15 to 25 degrees predominantly in a west and southwest direction. The approximate limits of the old channel can be followed for almost a mile, and the meandering course has a general west-southwest direction. The upper beds appear to be continuous for several miles and normally overlie the Comanchean series without apparent unconformity.

At a locality about three miles east-southeast of Kanopolis, Ellsworth county, Kansas, in the east bank of Smoky Hill river, near the west side of section 33, T. 15 S., R. 7 W., is an excellent exposure of the dark gray carbonaceous and fissile gypsiferous shales which contain cone-in-cone and are generally characteristic of the Comanchean series. The sandstone horizons are micaceous and contain fragmental plant materials. A deep channel cuts across this section and in the depression there is a medium- to coarse-grained, friable to hard prominently cross-bedded sandstone. The foresets have a general west-southwest inclination similar to those at "The Rocks", previously described. This is taken to represent the channel fill member of the Dakota stage.

Conditions similar to those described for the Dakota stage were operating in central Kansas during Comanchean time. The Marquette member of the Belvidere formation at the Natural Corral, McPherson county, Kansas, shows a distinct lens character. Zone 9, a part of the Marquette member, is described by Twenhofel[153] as "friable, fine grained, yellowish sandstone with a somewhat compact six inch band near the middle and another similar two inch band about 7 feet from the top. Locally the zone contains a little shale. It forms the upper portion of the cliff above the spring at the head of the east arm of the Corral, where it is thinner and more compact than indicated above. No fossils. Thickness 17 feet 6 inches."

Figure 31 shows a channel fill by the Marquette member about seven miles west-northwest of the Natural Corral locality. The Mentor horizon lies above this sandstone fill. At many localities near the adjacent corners of Ellsworth, Rice, McPherson and Saline counties

153 Twenhofel, Kans. Geol. Surv., Bull. 9, p. 32, 1924.

the Marquette sandstone member is irregularly bedded, lenslike, and fills depression in the underlying beds. This is to be noted particularly in SE. ¼ sec. 35, T. 18 S., R. 6 W., and NE. ¼ sec. 30, T. 18 S., R. 6 W., Rice county; SE. ¼ sec. 6, T. 19 S., R. 5 W., McPherson county; SW. ¼ sec. 35, T. 17 S., R. 6 W., Ellsworth county.

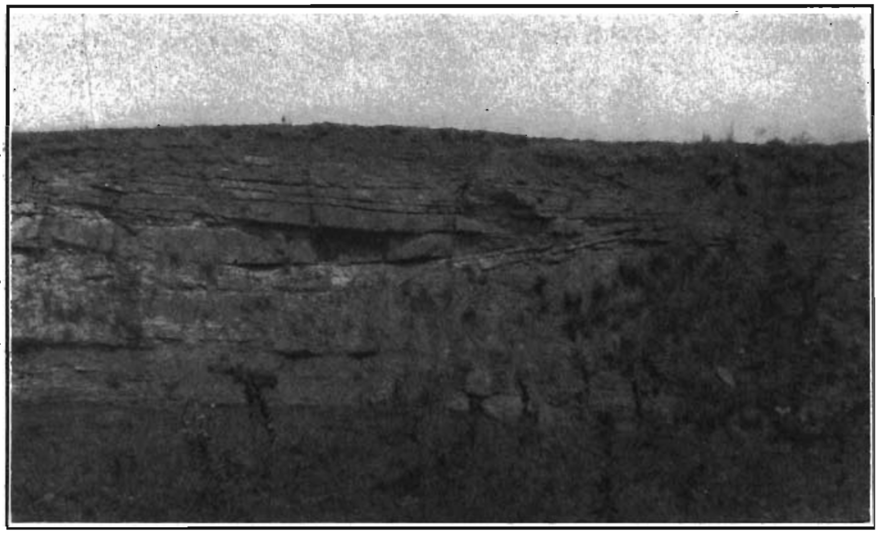

FIG. 31.—Erosion of clay and sands of Comanchean age filled by medium-grained evenly bedded sandstone of Marquette member. NE. ¼ Sec. 29, T. 17 S., R. 6 W., Ellsworth county, Kansas.

A possible exception to the interpretation of the sandstone lenses of the Marquette or Dakota as being channel fills as described in the previous paragraphs may be made in the case of the condition observed near Carneiro, Kansas. In an exposure seen in a road cut on U. S. Highway 40-S, in T. 15 S., R. 6 W., one mile west of Carneiro, Ellsworth county, the fine-grained evenly bedded sandstone and gray clays are definitely truncated by erosion and overlain by beds of medium- to coarse-grained reddish brown sandstone. The individual layers of the younger sandstone appear evenly bedded, with the thin parts of the bed pointing toward the clay bank but in detail minutely cross-bedded. The inclination of the units in the younger sandstones conforms to the slope of the truncation surface. Unfortunately, recent erosion has removed much desirable evidence. It is possible that this is merely another channel fill, with the beds sagging toward the center of the channel. However, a short distance to the south another exposure in a Union Pacific Railroad cut shows a similar truncation with the beds filling the depression and gradually flattening to a horizontal position away from the unconformity. About a mile farther south (see figure 32) the upper sandstone zones show regular foresets, inclined to west and southwest, with horizontal truncation planes and very thin horizontal beds separating the foreset zones. This indicates a deltaic deposit, and the writer interprets all the upper beds of this locality as being a part of a large alluvial plain merging with a delta. It is his belief that the younger sandstones seen in the cut on the Federal highway mentioned above belong to a series of long foresets, marking at that time the channel of a delta distributary.

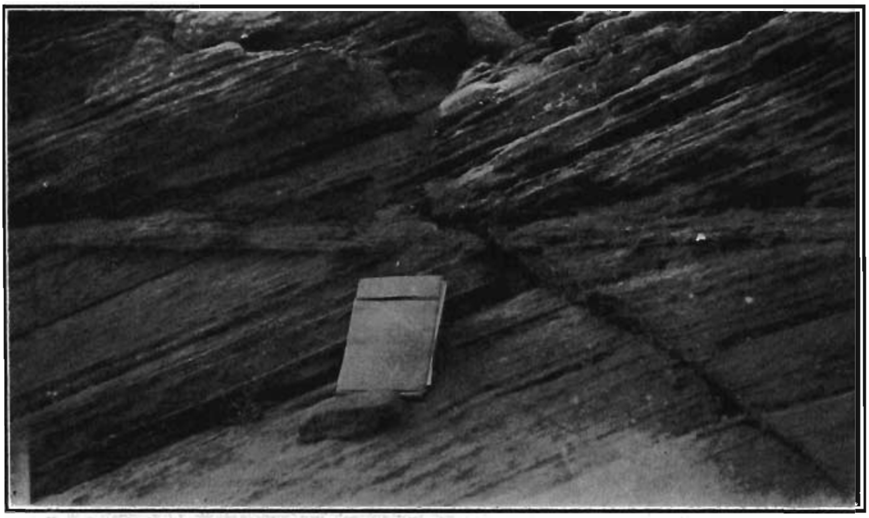

FIG. 32.—Regularly cross bedded sandstone, west of Carneiro, Kansas. Part of delta deposit. Note book is five by eight inches.

In summary, it appears that the coarse sandstone lenses were deposited in a previously provided low in the clay, silt or sandstone older deposits. In many cases the truncation of the alternating thin sands and clays of the older beds shows clearly that erosion was responsible for the low area or depression. The erosion may have been contemporaneous, due to the shifting and meandering of currents, and could have occurred in a stream channel, at a delta distributary, or in the near shore littoral zone. In other cases, where no erosion is apparent, or where the evidence is not conclusive either way, there are several possible explanations. The depression may have been one due to in-

FIG. 33.—Rocktown Channel Sandstone member interfingering with clays and sands of lower members. Sec. 11, T. 13 S., R. 12 W., Russell county, Kansas.

equalities of deposition, or have been a low area lying between two points or projecting fingers of a delta, or a channel-deep in an ordinary fluvial environment; as the new material was brought in by currents, or as the distributaries on the delta shifted their courses, these depressions may have been filled. In some cases the same current which

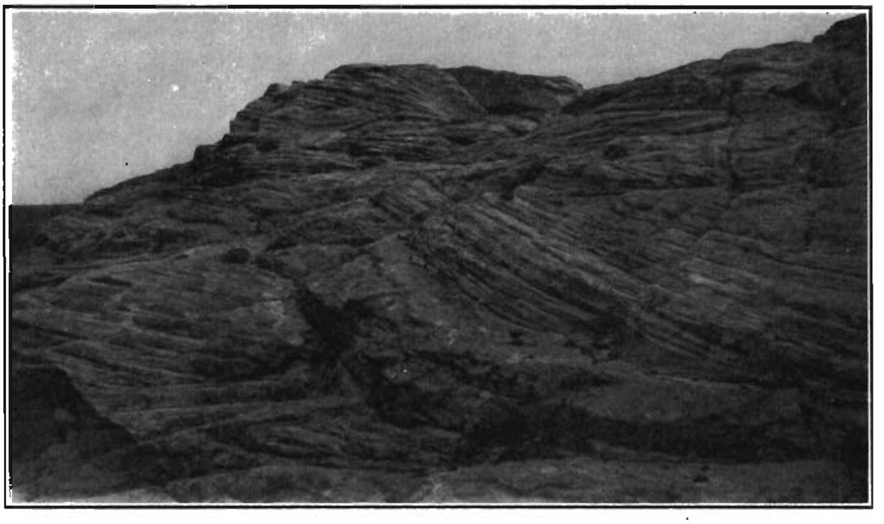

FIG. 34.—The Rocktown Channel Sandstone member in some exposures shows a complexity of cross-bedding. The variety of direction of foresets and truncation planes suggests the average conception of a wind deposit. The field relations indicate the fluvial origin of the beds. SW. ¼, NW. ¼, sec. 3, T. 13 S., R. 14 W., Russell county, Kansas.

brought the material to the site of deposition would rework the higher surfaces, wash some of the clay or silts into the depressions and develop an interfingering of the coarser deposits.

The net result of such interpretation is to yield a series of possible explanations, all of which show a close relationship and a relatively short time break, if any, between the two sets of deposits. Whether the later sandstone series is a stream deposit of rapid alluviation, stream bar, or littoral bar accumulation, the evidence indicates a certain contemporaneity of processes. It is apparent, also, that such conditions began earlier than the Dakota age, as the Marquette member of the Belvidere formation had the same history that has been outlined for the Dakota stage. Marine conditions intervened, however, between the Marquette member and the Dakota stage, as is evidenced by the Mentor member.

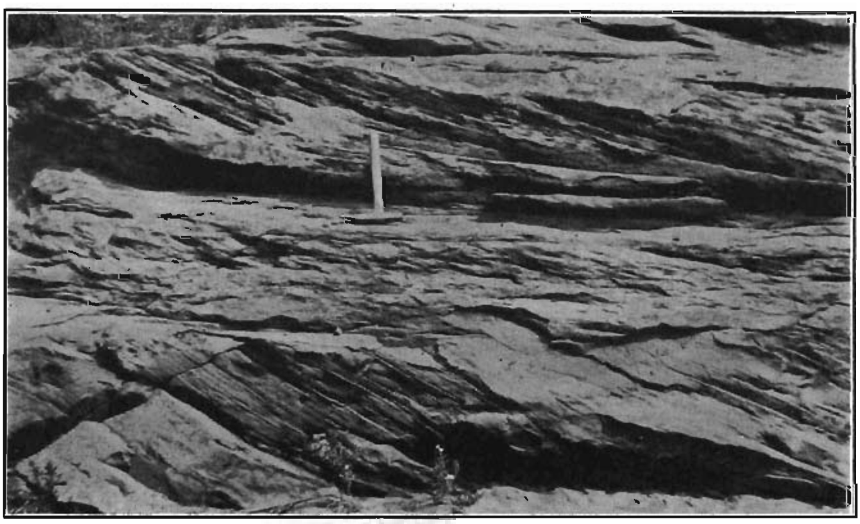

FIG. 35.—In many parts of the Dakota stage closely related to the channel deposits are regular zones of cross-bedding with uniform direction and amount of inclination. Such beds may represent the deltaic phases of the deposits. Sec. 27, T. 15 S., R. 9 W., Ellsworth county, Kansas.

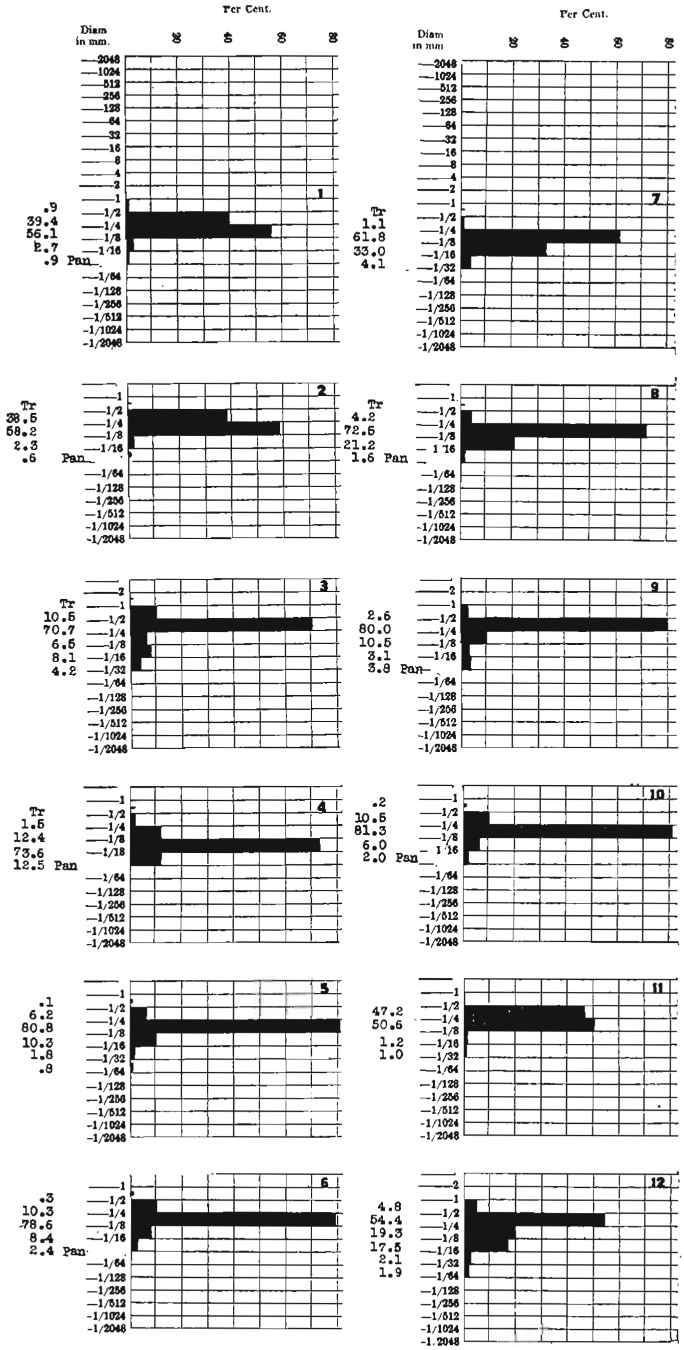
Per Cent.
Diam in mm.
1
.9
39.4
56.1
2.7
.9 Pan
2
Tr
38.5
58.2
2.3
.5 Pan
3
Tr
10.5
70.7
6.5
8.1
4.2
4
Tr
1.5
12.4
73.6
12.5 Pan
5
.1
6.2
80.8
10.3
1.8
.8
6
.3
10.3
78.6
8.4
2.4 Pan
7
Tr
1.1
61.8
33.0
4.1
8
Tr
4.2
72.5
21.2
1.6 Pan
9
2.6
80.0
10.5
3.1
3.8 Pan
10
.2
10.5
81.3
6.0
2.0 Pan
11
47.2
50.6
1.2
1.0
12
4.8
54.4
19.3
17.5
2.1
1.9

FIGURE 36

FIG. 36.—MECHANICAL ANALYSES OF DAKOTA SANDSTONE

No. 1. Rocktown sandstone member, Russell county, Kansas. Section 4, T. 13 S., R. 11 W.
No. 2. Dakota channel fill, "The Rocks," section 3, T. 19 S., R. 7 W., west of Little River, Rice county, Kansas.
No. 3. Dakota, channel sandstone, southwest Salina. Section 10, T. 16 S., R. 5 W., Saline county, Kansas. Bears leaves identified by Berry as of Dakota age.
No. 4. Dakota, channel deposit interfingering with side of channel. Section 22, T. 12 S., R. 13 W., Russell county, Kansas.
No. 5. Rocktown channel sandstone, near type locality, section 3, T. 13 S., R. 14 W., Russell county, Kansas.
No. 6. Dakota channel fill, section 33, T. 15 S., R. 7 W., east of Kanopolis, Ellsworth county, Kansas.
No. 7. Dakota, section 8, T. 31 S., R. 23 W., Clark county, Kansas.
No. 8. Dakota, 15 feet lower than No. 7.
No. 9. Dakota channel sandstone, section 9, T. 13 S., R. 12 W., Russell county, Kansas.
No. 10. Dakota, unconformably above Comanchean, section 31, T. 16 S., R. 3 W., Saline county, Kansas.
No. 11. Dakota, section 4, T. 30 S., R. 18 W., Kiowa county, Kansas.
No. 12. Dakota sandstone, channel deposit, section 8, T. 19 S., R. 7 W., Rice county, Kansas. Similar to No. 2.

CHAPTER VII

INTERPRETATIONS OF THE CONDITIONS OF DEPOSITION OF THE DAKOTA STAGE OF THE TYPE AREA

In making a review of the detailed stratigraphic sections of the Dakota stage in the type area, adjacent to Sioux City, Iowa, there are several facts which stand out as being significant to any interpretations which may be made concerning the origin of the rocks.

For convenience, the writer summarizes the most important of the facts which yield to interpretation.

1. The fact that the Dakota stage, as defined by Meek and Hayden and as observed by the writer, is conformable with the overlying calcareous fossiliferous marine shales and sandstones of the Graneros formation. Not only is it impossible to find any break in the section, but it is very difficult to place any arbitrary boundary between the two stratigraphic units. The recurrence of the thin evenly grained micaceous, glauconitic, molluscan-bearing sandstones in the 60 to 100 feet interval of shales between the lignite of the Dakota stage and the chalky limestones of the Greenhorn formation is indicative of the transitory conditions. The writer feels justified, therefore, in making the conclusion that the Dakota and Graneros are intimately related.

2. The presence in zone 6a, Section 1, at the Sioux City clay pits, of a marine molluscan fauna, associated with glauconite, in a part of the section which undoubtedly is a portion of the original Dakota "group" as defined by Meek and Hayden.

3. The presence of glauconite as a primary granular constituent in the sandstones at several levels of the typical section. Zone 6a, Section 1; zone 1, Section 2; zones 6, 7 and 12, Section 3; zones 4 and 10 (?) of Section 5; zone 1, Section 6; zone 4, Section 7; and several other scattered positions in isolated sections give typical examples.

4. The presence of dicotyledonous plant material in many of the horizons, some of which contain glauconite, and in the marine molluscan member zone 6a, Section 1. It is true that the zones which contain the best preserved and most complete leaves usually do not contain glauconite.

5. The occurrence of lignite zones at more than one horizon in the section and at all of the more complete sections of the type area, and the common occurrence of carbonized vegetable material or general lignitic substances in practically every arenaceous horizon in the sections.

6. The characteristic fineness of the majority of the sands, the high degree of sorting, the high angularity of the grains, the low percentage of accessory minerals other than glauconite and muscovite—all these appear as persistent features throughout the area.

7. The abrupt lateral changes in the sands and clays and their tendency to interfinger and to grade vertically are indicative of the delicate equilibrium of the conditions in the site of deposition, which with only a slight variation would change the character of the material deposited. This fact also makes it very difficult, and it might be said undesirable, to attempt any detailed correlation, zone for zone, between the different sections of the type area.

8. The presence in various sandstone zones of marks which may be interpreted as oscillation ripples, wave or swash marks, also the concentration of iron oxide in thin zones, many of which are parallel with ripple surfaces, truncation planes and foreset zones; all indicate the relative shallowness of the water and the possible occurrence of short periods of emergence.

9. The presence in several of the sandstone members of minor unconformities or diastems but the absence of any marked erosional channels similar to these described in the Kansas section.

10. With the exception of the significance of the mineral glauconite in several of the sandstone zones of the sections in the type locality, a study of the mineral content of the sands yields very little information. Numerous photomicrographs showing the physical nature of the sands, the glauconite and the cementing materials of the sand, and enumeration of the minerals in some of the specimens have been included as part of the detailed descriptions. Mention has been made frequently of the presence of grains of quartzite and chert of varying sizes, of basic feldspars and amphiboles, which is taken to be an indication that the sands of the Dakota type area had, at least in part, their source to the north and northeast. In southeastern South Dakota and adjacent Minnesota, about 80 miles north of Sioux City, the Sioux quartzite of Algonkian age was exposed during Cretaceous time, as is indicated

by the condition of overlap observed in the field and interpreted in well records. The relative abundance of basic feldspars may have a close correlation with the numerous exposures of diabase dikes in the southeast corner of South Dakota. The presence of a variety of minerals such as zircon, tourmaline, ilmenite, magnetite and rutile means little as they occur in varying quantities at different localities and are generally distributed through sediments of different ages.

At first the writer was skeptical concerning the validity of his identification of the mineral glauconite, but comparison with sections and grains of the same mineral in various stages of decomposition from sediments in Kansas, New Jersey, Texas and Wisconsin served as a check on the identification of the mineral in the Dakota type sands. There seems to be little question that the glauconite in the several members of the Dakota stage was formed on the site of deposition of the sand. In one or two instances, however, the evidence is not so certain, and it is possible that a few grains of weathered glauconite which were observed in some of the lower sands of the Sergeant Bluff Section 5 and the Homer, Nebraska, Section 10 were derived by the erosion of a nearby glauconitic sandstone. The mineral is so fragile and easily weathered that it is doubtful if it could stand a very long period of transportation. The writer knows of no fresh glauconite which occurs in rocks of other than marine origin. Glauconite sometimes develops by the alteration of an alkaline feldspar, but such development can be observed when the grain is studied in thin section. Such alteration was observed by the writer in a thin section taken from zone 9 of Section 1, which is at the top of the Dakota or base of the Graneros formation.

It is difficult to make correlations of the individual zones represented in the different detailed sections presented in this paper. As appears in the study of any single exposure the lensing and interfingering of different types of rock are pronounced, and it is even difficult to compare two sections within a few hundred feet of each other, except by noting the position relative to a given datum. Thus the lack of any persistent horizon makes it unwise to attempt a detailed matching of the sections.

It has already been shown that it is undesirable to attempt to use the contact between the base of the Graneros and the top of the Dakota as a means of correlation, as this zone does not have a definite position. Any division between the Dakota and Graneros is purely arbitrary, and the writer believes that such a division is unnecessary. Observations in the Kansas area substantiate this conclusion. At many places where a section includes the Dakota and Graneros, the former grades into the latter. It is true that the Graneros shales are almost everywhere dark gray, carbonaceous, fissile, with sandstone lenses, and have a few invertebrate fossils which are more distinctive of the Colorado stage.

The base of the Dakota stage in the type area is not exposed, and it is uncertain from a study of the poorly preserved well records just where it may be. Indications are, however, that the Dakota ranges from 100 to 300 feet in depth below the surface in the type area. It is interesting to note, however, that wherever the Dakota is found resting on older rocks, the interval to the overlying Graneros is normally much less than the figure of 400 feet which is frequently given for the Dakota of Nebraska, Kansas and Iowa. The writer is of the opinion that when more careful records are taken and a thorough study is made of the well cuttings from drillings which penetrate the full division of the Dakota in northern Kansas and Nebraska the average thickness will be found to be approximately 225 to 250 feet. The occurrence of 50 to 100 feet of sandstone and interbedded shales in one locality, 100 or more feet of clays and silts in another locality, with 50 to 100 feet of sandstone overlying the clay in several cases, has led some geologists to believe that the Dakota is divisible into three members, and that the thickness is the total of the three divisions. The writer's observations, as has been indicated in the present paper, cause him to be strongly of the opinion that the clay zones are frequently the equivalent of the sandstone zones, either the so-called upper or the lower sandstone.

The general change in the character of the deposits from one point to another may be appreciated by comparing the writer's Sections 10, 8, 7, 5, 4, 1, 2 and 3 (see Fig. 25). This series of sections starts southwest of Homer, Nebraska, takes in the west bluff of Missouri river to the Aowa creek section, the east bluff of the Missouri from Sergeant Bluff north through the Sioux City pits to the section in southern Plymouth county on Big Sioux river. The differences in sections when considered as a whole show the dominance of sandstone in the south and as far as the Prospect Hill section at Sioux City, with finer grained and more argillaceous beds to the north and west, as seen in the Aowa creek section 7, the Stone Park Section 2, and the Plymouth county Section 3. The upper part of the Sergeant Bluff Section 5 is dominantly sandy, while the lower portion contains a large amount of shale, clay and silt.

The only factors which might be termed consistent in any of these sections are the lignite beds as seen at Sergeant Bluff and the Sioux City pit, and the reddish brown glauconitic 20- to 24-inch sandstone layer which can be traced from Sergeant Bluff to the Sioux City pit, thence to Stone Park and to the section in southern Plymouth county. At the base of the section along the south bank of Missouri river, zone 1 of the Elk Point Ferry Section 6 contains the marine fossil horizon and glauconite, as described above. Zones 4 and 5 of Section 7 and the top zone of Section 10 south of Homer probably are equivalent to this sandstone. As this is the member which carries the marine invertebrates at the Sioux City pit, the belief is that at this one period at least an embayment occurred in the Sioux City area.

The lignite which occurs in zone 9 of the Crill Mill section of southern Plymouth county may be the same as zone 7 of the Stone Park Section 2, which in turn may be near the same position as the lignite of zone 5, Section 7, near the mouth of Aowa creek. This lignite lies at the base of zone 7, Section 2, and below zone 12, Section 5, either of which the writer believes is correlative with zone 6a of Section 1. As seen in Sections 1, 3 and 5 there are lower lignite horizons which may be at about the same position. In Section 7, at the mouth of Aowa creek, there is a higher lignite which does not seem to have any correlative in the other sections.

The presence of the lignites low in the stratigraphic section, again in the middle of the sections, and in one case in the upper part of the section, and the large amount of lignitized and carbonized vegetable material which occurs in large fragments and as small accumulations in depressions in the sandstone and silt in many parts of the exposures indicate the recurrence of swamp or lagoon conditions favorable to the accumulation of vegetable material under water. The presence of a fine-grained sandstone with glauconite, and, in at least two localities, with marine invertebrates, indicates a marine extension at least once during the Dakota age. The occurrence of glauconite in the various sands is taken as proof of their marine origin. It is true that a glauconitic sandstone at one point, as for instance at Aowa creek, may have for its equivalent a series of alternating fine sands and silts at another locality, as at Homer.

The section at the foot of Prospect Hill in Sioux City, with its dicotyledonous flora, and the sandstone zones which carry the same type of leaves at Sergeant Bluff, the Sioux City pit, and along Big Sioux river do not necessarily prove the terrestrial origin of the sediments. The occurrence of some well preserved leaves suggests, however, that land was not far removed and that at favorable times the leaves floated out to be deposited in the lagoonal and deltaic sites of accumulation.

The direction of the motion of the currents which were depositing the sands in the type area may be interpreted in part by the direction of inclination of the foreset beds of the cross-bedded zones. Such inclinations have a wide range and may be found facing the southwest, west, north and northeast. This would leave the southeasterly and a part of the northeasterly quadrants as possible directions from which the transporting currents came. When the sections southeast of Homer and southward toward Decatur are considered, the direction of the inclination of the foresets is seen to change to face the southwestward and southeastward quadrants, thus suggesting a swinging of the shore line toward the southeast in the area southeast of Sioux City.

In summing up these statements and interpretations the writer concludes that the type area of the Dakota stage represents the sediments laid down in an environment at and near the shore line of a broad, relatively shallow ocean. The material was derived from the north and northeast and was carried southward by streams of small competency which may have had wide flood plains and which when reaching the coast line built wide and ramifying deltas. At times these deltas extended themselves seaward with a development of barlike fingers of relatively coarse material, with the minor distributaries of the streams throwing off the finer silt and clays which were deposited on the flank of the principal distributary. Such a finger is believed to occur in the north-south zone which is indicated by the Prospect Hill and Homer sections. During at least one time the sea advanced over the deltaic and littoral deposits to and probably beyond the Sioux City area and deposited a glauconite sand with marine invertebrates. That the sea advanced from the west, southwest and south in this area is indicated by the direction of the foresets in the accompanying current deposits. How far south this sea extended the writer is uncertain. However, the fact that the marine invertebrates at Sioux City show close relations to parts of the fauna of the Mentor formation of Kansas indicates that there was a common source of the fauna and that the seas were at least connected. The writer has been inclined to believe that the Sioux City sea was not continuous into southern Nebraska and central Kansas, but that possibly a peninsula projected westward from southern Iowa into central Nebraska and separated central Kansas from the northwestern Iowa embayments. In this case the principal advance of the sea in the Sioux City area would be from the west and southwest, and the gulf would have a shore line which would trend to the southeast from Sioux City and swing westward from southern Iowa into central Nebraska. The coarse deposits of the Coburg, Lewis and other southwestern Iowa localities represent the deposition of the westward- and southwestward-flowing streams. These streams made their deposits and extended their deltas for a short period over the thin marine bed represented by zone 6a of Section 1. A second definite sea invasion followed which marked the beginning of the conditions which were ultimately to characterize the Graneros, Greenhorn, Carlile and Niobrara deposits.

The brief descriptions and references to the Dakota of southern Nebraska and central Kansas were included to show that the deposits of those regions have some characteristics in common with the Dakota stage of the type locality and also show some marked differences. However, there is no question in the writer's mind but that the history of the Cretaceous rocks below the Graneros of Kansas, when considered in a single picture, represents conditions which were not unlike those of the Dakota of the upper Missouri country. That is to say, a near shore, littoral, marine and terrestrial environment existed in Kansas, and coarse sand, silts and clays and lignites were deposited in that environment; but it occurred at an earlier time than the deposition of similar sediments in a similar environment in the Sioux City area.

Twenhofel[154] has shown that the Kansas sediments of this type include several members which carry a marine fauna of a definite age

[154] Twenhofel, Kans. Geol. Surv., Bull. 9, 1924.

The equivalency of this fauna to the Washita of Texas has been established. At the same time the age of the youngest part of the Dakota stage of Kansas appears to be that of the type Dakota, based on the floral content.

Whether the shore line on the eastern edge of the Dakota embayment had a direct course from eastern Kansas to midwestern Iowa, or whether it curved northwestward from eastern Kansas to central Nebraska around the peninsula and then curved back to the east in western Nebraska, extending on up into Minnesota, the fact remains that the accumulation of the Dakota type sediments was made at about the same time as the accumulation of the Belvidere formation and the delta and river deposits of the Dakota of Kansas.

The writer favors the theory of the contemporaneity of the type Dakota and the Dakota and Belvidere of Kansas, rather than the theory of a progressive overlap from Kansas northward to Nebraska. It would have been impossible for the latter condition to occur with the deposition of sands by streams in Kansas at a time when a glauconitic sandstone was being accumulated in a marine environment in Nebraska; the close relationship of age being established by the dicotyledonous flora and also by the close affinities of the invertebrate faunas. Another viewpoint might be taken by considering the Graneros and Greenhorn formations. In Nebraska and northwestern Iowa the Graneros formation is merely a transition from the Dakota, and there is small difference in the relative ages of the two, as indicated by the affinities of the pelecypods in the glauconitic sand layers in the gray shales at the base of the Graneros. In Kansas the Graneros overlies the Dakota with apparent conformity and is also a transitional sediment. Where the Graneros occurs above the Rocktown Channel Sandstone member the only break or apparent unconformity, except the gradual change in lithology, is found at the base of the Rocktown member. If this nearly continuous deposit represented an accumulation in a gradually advancing and overlapping sea, the deposits of the southern area should be much older than those of the northern area. This does not appear to be true; first, because of the presence of a similar dicotyledonous flora in both areas; second, because of the presence at Sioux City of marine invertebrates which are closely related to the invertebrates contained in the Mentor member and in a sandstone at the top of the Dakota stage of central Kansas and in the formation just below and closely related to the Rocktown member of Kansas. There may have been in early Graneros time an overlap of a rapid nature which moved toward the southern and northern area simultaneously from the west. This possibility is suggested by the character of the deposits, the direction of inclination of the foresets, and the extent of the channel deposits of the Dakota stage of Kansas and northeastern Nebraska. However, the writer has not made sufficient studies in the areas west of Kansas and Nebraska to discuss this viewpoint.

The Position of the Dakota Stage in the Upper Mesozoic Sequence

The primary purpose of this paper is not to define the relations between the rocks which have been called Comanchean and sometimes included as a separate geologic system, or to argue the question of the validity of the division of the Cretaceous of central North America into two systems. However, certain facts and relationships concerning this question may be gained from the data presented in this paper. Other data which the writer has accumulated and has not presented here, because of the limits of this work, also serve as a basis for the writer's opinion.

Using the Kansas, Nebraska and western Iowa area as a background, the writer is convinced that the Washita-Kiowa-Mentor series belongs to the same general sequence as the Dakota stage of the type area. Also, because of the close relationships and the similar physical history of the "Dakota" (using the term in a narrow sense) rocks of Kansas and the Kiowa-Mentor series of Kansas, it seems impractical to make a systematic separation in that part of the geologic column.

The affinities of the fauna which occurs in the rocks of the type section with that described by Stanton from the Dakota sandstone in northcentral Kansas and in turn with some of the species of the Mentor sandstone of central Kansas, and the occurrence of typical Dakota flora in the clays which lie below the channel member of the Dakota in Kansas and are closely related to the Belvidere clays and sands, all tend to substantiate the conclusion that the entire section is too intimately related to bear a major geologic division.

The writer places the Washita-Kiowa-Mentor-"Dakota" rocks of

Kansas in a stage at the base of the Cretaceous system. This stage may be considered a part of the Comanche series. The Dakota of the type area may be in part younger than the oldest part of the stage in southern Kansas and younger than the lower part of the Comanche series of Texas; it is at least as old as the Mentor member of Kansas, and apparently is closely equivalent to the entire Kansas section.

CHAPTER VIII

AN EXPERIMENTAL STUDY OF FLUVIAL SORTING AND DEPOSITION

The question of how to sample a sedimentary rock for analysis is difficult to answer. Also, it is difficult to be certain if the sample is representative of the conditions under which the material was de-

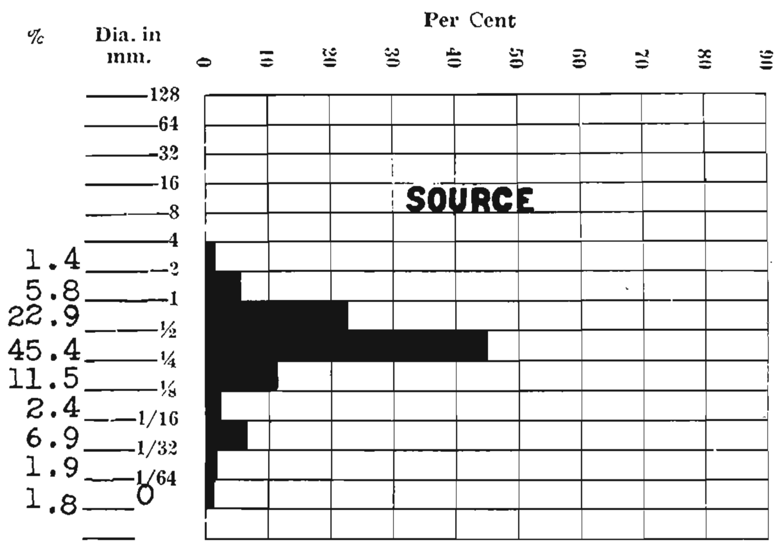

FIG. 37.—Analysis of source material for Experiment No. I.

posited. In dealing with cross-bedded sandstones one can take many different types of samples. A sample taken from a vertical zone at right angles to the direction of the depositing current and a sample from the same position but parallel to the current may show some differences;

The experiments described in this chapter were performed in the spring of 1929. Since that time a new stream table has been installed in the sedimentation laboratory. The new table is built of sheet steel, rigidly supported by heavy steel beams mounted on capstan jacks. The tank is 21 feet long, 7 feet wide, with sides 12 inches high at the low end. The steel trough is joined with a depositional basin 7 feet wide by 8 feet long and 2 feet deep which has glass sides and a concrete floor. The jacks serve to change the gradient, with a flow either to or from the depositional basin.—March, 1931.

a sample taken from a single layer or foreset zone may be distinctly different from a sample which represents a composite of several or all of the foreset zones of a single unit of cross-laminated beds. Samples taken from different parts of river channel and bar deposits show different types of mechanical analyses.

In order to study the variety of analyses obtained under known con-

TABLE I

Mechanical Analyses for Experiment No. I

Sizes in mm.	A	1	2	3	4	5.	6	7	8	9	10
4-2	1.4			1.0	0.7	0.8	0.9	3.2	2.4	0.3	0.5
2-1	5.8	1.6	1.5	4.2	3.1	13.8	4.8	13.9	8.2	2.0	1.4
1-½	22.9	16.3	16.2	27.2	23.9	46.8	36.8	28.1	31.0	24.6	16.0
½-¼	45.4	41.0	45.4	51.2	53.1	33.1	42.2	26.0	38.2	54.9	55.0
¼-⅛	11.5	14.3	13.8	9.4	10.7	1.8	8.8	5.9	13.2	11.5	17.0
⅛-1/16	2.4	6.2	5.3	1.5	2.8	0.3	2.3	2.5	3.4	1.7	3.2
1/16-1/32	6.9	18.2	12.6	2.5	4.2	3.4	3.5	13.0	2.9	3.1	4.7
1/32-1/64	1.9	2.0	4.3	0.8	0.7		0.5	4.2	0.6	0.7	1.0
1/64-0	1.8	0.4	0.9	2.2	0.8		0.2	3.2	0.1	1.2	1.2
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

A—Source materials, average of 3 samples.
1—Top center near head of delta.
2—Top of delta center, similar to No. 1.
3—Top of delta near source, left hand corner.
4—Top of delta near source, right hand corner.
5—Left side, center of delta.
6—Center head of delta vertical section, upper half, transverse to current.
7—Same as No. 6 but lower half of delta, transverse to current.
8—Same location as No. 6 but parallel to current.
9—West slope of delta, ½ inch foreset zone.
10—Top of channel bar downstream point.

ditions of river transportation and deposition, the writer performed some simple experiments with the stream table in the sedimentation laboratory at the University of Iowa.

The stream table used for these experiments is a long, shallow, flat bottomed, horizontal trough, measuring 13 feet long, 3 feet wide and 7 inches deep. The trough is lined with sheet tin and is water tight. The bottom of the trough is horizontal and relatively even, except for a few minor bulges in the tin work. At one end is a basin with an outlet which can be changed to maintain a constant water level at different depths in the trough. The water enters the table as a spray or from a lakelike reservoir at the end opposite the outlet.

STREAM TABLE EXPERIMENT NO. I

The upper half of the table was filled with sand so as to make a bed over which the water would flow from the reservoir at the head. The crude channel prepared in the sand had a very steep gradient with an abrupt reduction at the edge of the sand bed. The outlet level was

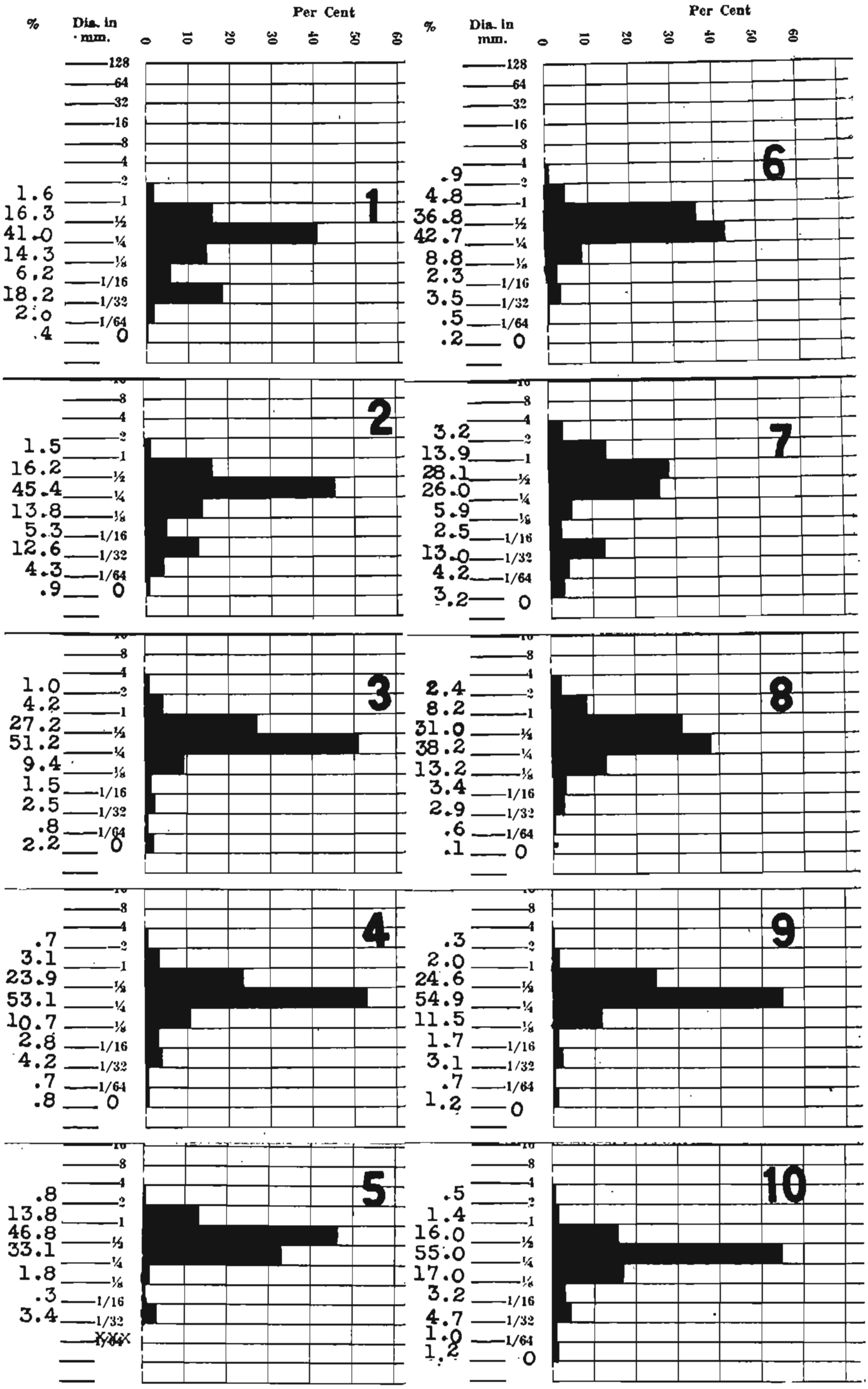

Fig. 38.—Mechanical analyses of deposits in Experiment I. See Table I for explanation.

raised so that approximately 3½ inches of water stood in the table below the sand bed area. The effect was a rapidly flowing stream carrying a heavy load which was deposited on the growing delta. The delta was approximately 12 inches across and 16 inches long when it was completed and the samples were taken. A number of samples taken from various parts of this delta were analyzed and compared with the analysis of the sand being eroded.

The analyses in Table I and plotted on figures 37 and 38 speak for themselves. There are important differences in the deposits as indicated by the graphs, even after the minor distinctions are eliminated by the use of a small plotting scale.

Samples 1 and 2 are similar and were taken from nearly the same position and from environments also identical. The analyses of these two sediments show that under similar conditions a similar assortment of sand is deposited.

Analyses 6, 7 and 8 make an interesting comparison. Numbers 6 and 7 are from a vertical zone which was transverse to the direction of the depositing current, but number 6 represents a zone 1½ inches deep, including the top, and number 7 is a one-inch section immediately below. The difference in the analysis includes a shift of the primary or maximum grade from the usual one-half to one-fourth mm. grade in number 6 to the 1–½ mm. grade in number 7. In general number 7 is a coarser sand with over three times as much material in the two coarser grades and with the maximum grade occurring in the 1–½ mm. grade. However, number 6 has 85 per cent of its material larger than ¼ mm. and number 7 has only 71 per cent in the same range. Number 7 differs also in the prominent secondary maximum in the 1/16-1/32 mm. grade.

In the case of samples numbers 6 and 8 the specimens were taken from nearly the same position with regard to the head of the delta and represent a vertical section 1½ inches deep, including the top. Number 6 sample came from a face one inch wide transverse to the current direction, and number 8 came from a face two inches wide and parallel with the current. The differences in these analyses are very slight, the small increase of material in the finer grades below 1/8 mm. in sample 8 being due probably to the slightly greater distance from the source of a part of the sample.

Samples 3 and 4 show similarities in their size composition. The positions on the delta with regard to source and depth of sampling were nearly the same except that they were from opposite sides and were deposited by different distributaries.

Sample 9 is from a thin zone of foresets and was taken parallel with the bedding. It is probably more distinctive of a single set of conditions than any other sample of the group. The current and volume of the distributary were nearly constant during the deposition of this single foreset bed. The degree of assortment of the sand is shown by the presence of 55 per cent of the entire sample in the ½-¼ mm. grade and 79 per cent in the grades between 1 mm. and ¼ mm. There is a close similarity to sample 4, which is from the top of the delta and in reality represents the material in process of transportation to a foreset zone at the time the water current was shut off. Sample 10 is of a different type than those described above. It is from the stream side of the downstream point of a bar in the channel above the delta. The analysis when compared with that of the source material shows the effect of a sorting action with a concentration of a greater amount of material in the ½-¼ mm. grade and the removal of the coarser grades. The subsidiary grade of ¼-1/8 mm. is greater in the case of the bar deposits than in the source material.

In summary, it appears that some caution should be exercised in taking samples and that careful note should be made with regard to the structural relations of each sample. This is true particularly in the case of foreset beds. It is not always possible to know the exact relationship of any specimen to the head of a delta or to the distance from the farthest removed distributary, but it appears from these analyses that these facts are less important in the ultimate interpretation.

The statement of this experiment does not intend to exclude the facts that the conditions represented here on a small scale do not exactly duplicate the natural environments and that conclusions drawn from such experiments may differ from conclusions based upon accurate observations in nature. However, such experiments do tend to demonstrate the need for more measurements of natural conditions.

STREAM TABLE EXPERIMENT NO. II

The sand material used for this experiment was spread out more or less unevenly over the stream table with a gradual decrease in thickness from the head of the table to the foot or the basin end. At the head the sand was approximately eight to nine inches deep, while at the foot there was only about one-half inch of material. A broad, indistinct meandering channel was made in this sand bed, so that as the water flowed from the reservoir at the head there was a tendency for it to follow in this lower course. In other words, a consequent stream was developed.

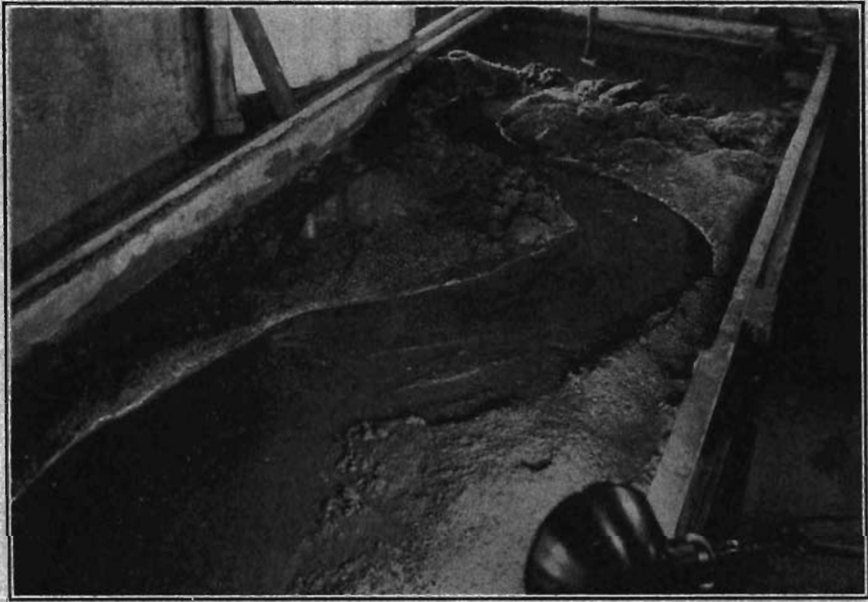

FIG. 39.—A view of the river taken at an early stage of Experiment II, before cutting through the bank on the right middle and left background. Compare with Figure 40.

The water was allowed to flow continuously for nearly one hundred hours, during which time the stream meandered, changed its course, built and removed bars, and in general developed a flood plain similar to that seen in rivers of the Platte river type. Figure 39 shows an early stage of the stream on the upper half of the table. It will be noted that the water is very shallow and that in reality there is considerable tendency for the braiding of the channel. Figure 40 shows the stream table with well developed channels at the close of the experiment. This view was taken from about five feet above the table and the background is considerably foreshortened.

Figure 40 shows the position of a series of samples which were taken to represent the different types and conditions of the stream deposits. Additional explanations are given in the following pages.

FIG. 40.—View taken from basin end and about five feet above stream table, showing all parts of stream and location of samples.

Figure 41 shows in greater detail the character and position of samples B, C, D and E. The analyses of these samples are grouped in figure 42, and the percentages are tabulated in Table II.

All samples were taken from an area approximately two inches square and included the material in the upper one-fourth to threeeighths of an inch. Samples were dried and analyzed for both their sand and clay content.. The regular method of subsidation and screening is described in Appendix A.

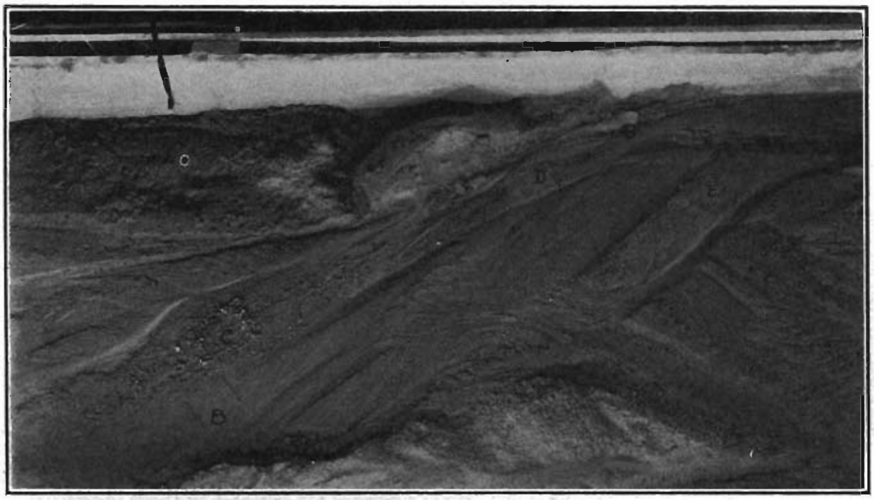

FIG. 41.—Detailed view of central part of stream showing position of samples B, C, D and E.

Sample A.—Taken near the basin end of the stream table from a part of the channel which received only a side current, which at times of overflow would have a trend of 60 to 75 degrees to the right of the main current. Fine material would be deposited over the coarse, tending to settle between the coarse grains. In the photograph the coarse grains are more apparent.

TABLE II

Mechanical Analyses for Experiment No. II

Diam. in mm.	A	B	C	D	E	F	G	H
8-4			6.0					
4-2	0.8	1.0	12.0	0.8	0.7	1.7	Tr	2.1
1	1.4	2.8	25.1	2.2	2.1	11.6	1.0	5.4
1/2	20.5	21.8	29.2	21.0	30.1	45.7	21.4	25.3
1/4	49.8	44.3	18.6	51.4	48.2	25.9	51.8	31.0
1/8	10.7	11.4	3.7	13.5	6.7	2.8	14.7	7.1
1/16	2.7	3.3	1.4	3.6	1.4	1.3	2.7	2.3
*1/32	14.1	15.4	4.0	7.5	6.7	11.0	8.4	12.7
1/64					2.3			8.0
—1/64					1.8			6.1
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

* In the analyses which do not show percentages below the 1/32 mm. grade no separation was made and all that passed the 1/16 mm. screen was caught in the pan.

Sample B.—Taken from a bar in the main channel on the left side of the main current. The angle between the main and bar currents was about 25 to 30 degrees. In the photograph, figure 40, the material

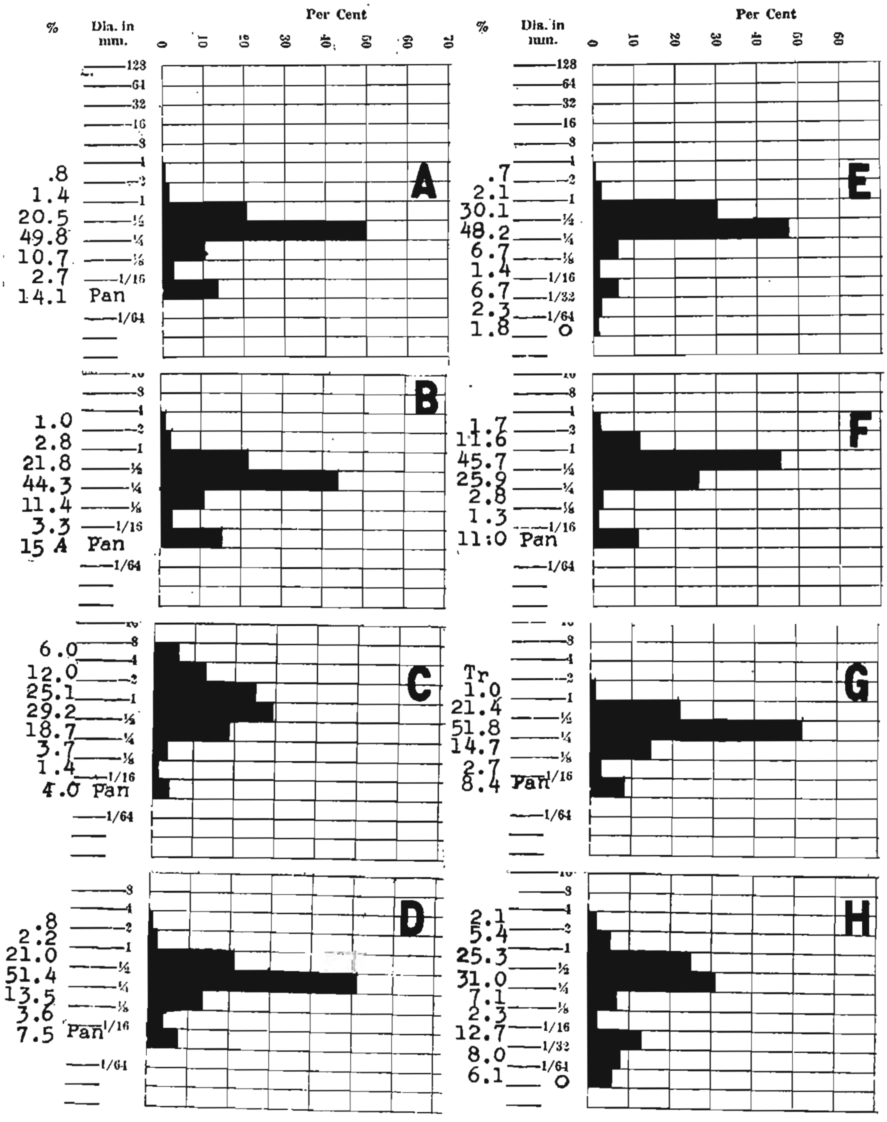

FIG. 42.—Mechanical analyses of deposits in Experiment II.

appears finer than that of sample A, but the analysis shows that it is slightly coarser. Sample B included a part of the coarse-grained bar nucleus which had been covered with the finer sands.

Sample C.—Taken to the right of B but in the main channel. The material in the stream bed grades downward to finer sand which was deposited when the main current was near the right hand bank.

Sample D.—A bar sample from the last principal channel about midway in the length of the stream. Just below this sample at the point of the bar the sand was much coarser. The coarse material was carried along the edge and over the top surface of the bar. Sands of a more typical size grade distribution gradually migrated downstream to cover the coarse deposit. Such action results in a nucleus or center of coarse sand veneered with finer and better sorted material, as indicated by this sample.

Sample E.—Another bar deposit but considerably older than the last flow; as seen in the photographs the position of E is at the top of a terrace. At the time of deposition this was a part of the main channel though slightly to the left of the strongest current. The coarser material was spread to the left in a manner similar to the conditions by which sample A was formed. The stream did not maintain this channel very long but owing to influences upstream was shifted to the right.

Sample F.—A coarse sample from a wide fanlike deposit below the break in the stream bank. This break simulated a levee break in a large river at flood time. The waters spread rapidly and deposited the major part of the load near the break, the coarser particles being carried to the outer edge of the fan. Study of the photograph (Fig. 40) will show the remnants of this fan after dissection by a younger channel near G.

Sample G.—A bar deposit, the sample taken from near the inside edge, the stream tending to slip off to the right bank. The relations are very much the same as in samples A, B and D.

Sample H.—An old bar deposit of one of the early channels. The stream at time of deposition had a large volume and was eroding vigorously a large bank that included much very coarse sand and considerable loess. The point of erosion was at a sharp bend in the stream, and the bar was deposited just below in the straight part of the channel.

The variety of analyses is interesting; certain types are readily recognized, and in general there are certain persistent features. The bar deposits as shown by samples A, B, D, E and G have several points in common. The maximum occurs in all cases in the ½-¼ mm. grade and although it ranges from 44 per cent to 51 per cent the average is 50 per cent. The principal subsidiary grade in all five specimens occurs in the 1-½ mm. range, and in all cases there is a smaller subsidiary grade in the ¼-1/8 mm. range. The secondary maximum occurs in the 1/16-1/32 mm. grade. The exact proportions are indicated best in sample E.

Specimen C is decidedly unlike any of the other materials. Inspection of figure 40 shows that C is in the position of the last channel. The extreme coarseness of the sample and the apparent lack of sorting are probably due, in part, to the general lack of fine materials and the catching in the rough irregular bed of more large grains than usual. Observations made while the stream was running demonstrated clearly that the larger grains were being transported from the upper sources and because of irregularities in the bed became lodged at this point. The large grains which worked loose were carried away and were deposited at the edge of the drainage basin. The main portion of the finer grades was carried by the weaker currents to the left and deposited on the bar position of sample B.

Sample H does not conform to the bar deposits first described, although it came from a position which probably at one time represented a bar in the channel near the source of the stream and just below a bank in the process of erosion. At the time the sample was taken the position of H was that of a high terrace and the course of the stream had been changed greatly. The high percentage of coarse materials above the ½ mm. grade probably is the result of a fresh load deposited just around the bend from the cut bank or point of origin of the coarse grains. The presence of nearly 27 per cent in the silt and clay grades is the result of erosion of a loess bank adjacent to the gravel bank against which the stream was cutting.

Sample F is anomalous in the fact that the major grades occur in the 1-½mm. grade rather than the ½-¼ mm. grade as seen in the other specimens and in that the principal subsidiary grade is in the ½-¼ mm. range, or below the maximum grade instead of above it. The large secondary maximum in the silt grade is in part due to the fact that this sample was not analyzed by subsidation. The deposit of this material followed a break in the levee-like bank through which the stream cut. The channel shifted immediately, the stream spreading out and depositing its load abruptly in much the same manner as an alluvial fan.

STREAM TABLE EXPERIMENT NO. III

In the previous experiment it was observed that large coarse grains of sand tended to move farther downstream during a given period of time than the much smaller grains. At first it was thought that this observation did not fit with the general conception of the size and amounts of materials carried by a stream of given competency. In order to study this action more carefully, the writer constructed a meandering channel of plaster of paris set in a sand mold on the stream table (figure 43). The plaster of paris was allowed to set and dry thoroughly and later given several coats of shellac. A small amount of fine sand became mixed with the plaster of paris when the cast was being poured. The sand added to the roughness of the bed, which had an even gradient or fall of 2 inches in 10 feet. The length of the channel cast was 14 feet. The velocity of the water at 1.5 gallons per minute was 0.9 foot per second. The volume was varied for different parts of the experiment.

A washed river sand which had been screened to remove the very coarse grains was used in all parts of the experiment.

With the solid bed and sides no material could be picked up by the stream, so any sample taken from a channel deposit was a true representative of the material transported from the source, and any sorting that occurred en route was free of outside contamination. An average of six samples taken from the source materials is given in Table III in conjunction with the tabulation of other analyses.

Samples were taken at various points in the channel where the bars formed. Figure 43 shows the bars after a 30 minute run. The points of curves are numbered downstream 1, 2 and 3, and the numbers given to the samples refer to the bars which formed in the straight part of the channel just below the curve points.

Numbers 1, 2 and 3 of Table III are the analyses of the materials deposited below the curves after a five minute run at average velocity and volume. This time period was sufficient to form bars large enough to sample. A very small bar formed at the point of curve 3, but the amount of material was less than two grams; the dozen or so

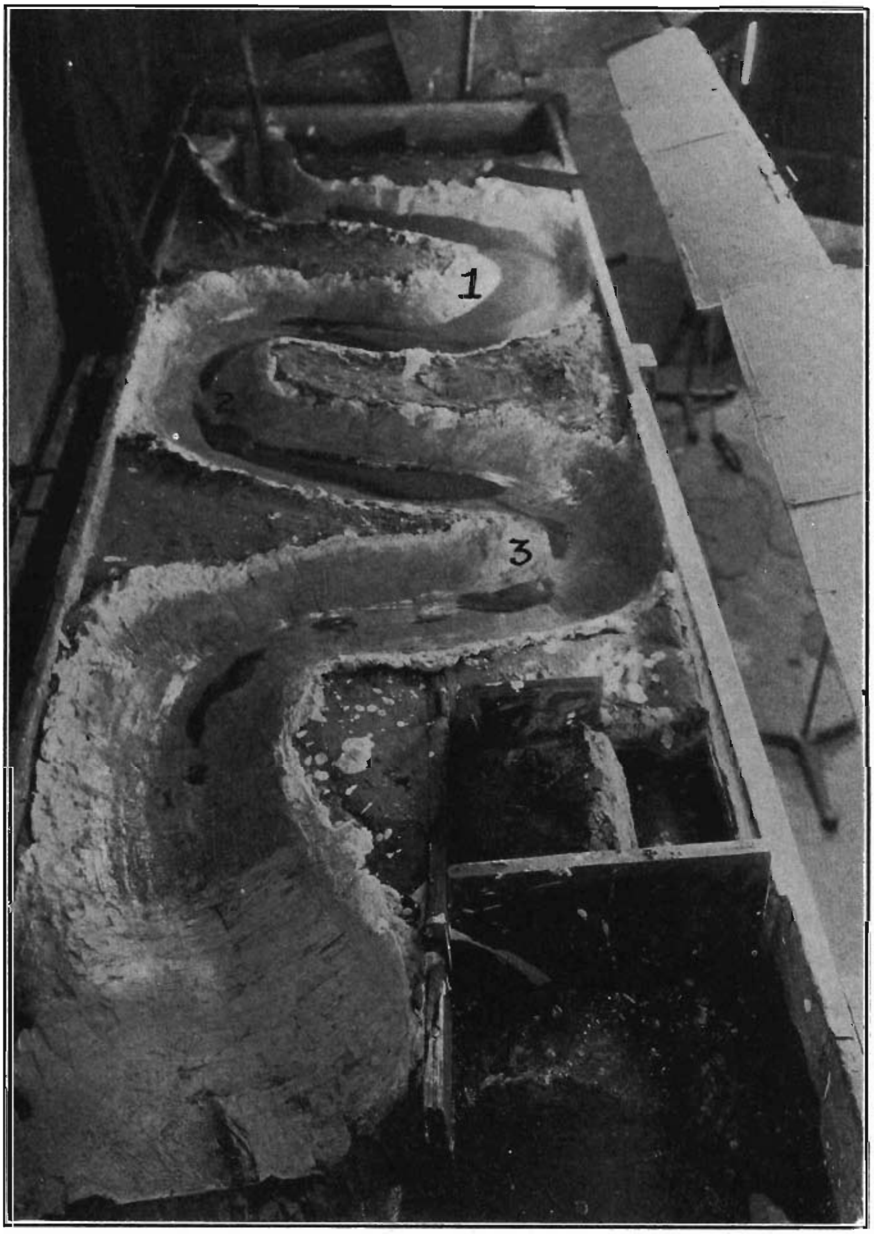

FIG. 43.—View showing the position of bars after a run of 30 minutes in the plaster of paris channel.

grains which came to rest at curve 3 were almost entirely of the 2-1 mm. grade. The three analyses (1, 2 and 3) of the material deposited during this short run show without question that the greatest concentration of the coarse load during any definite time period occurs downstream. The source material fed to the stream was handled quickly by the current, and by direct observation one sees the rapid transportation of the largest particles and the slower but more massive movement of the finer materials. The rate of movement of the large grains is almost that of the flow of the stream, a large grain reaching the end of the channel in 18 seconds after the material was fed at the head. The velocity of the water was 16 seconds for the length of the channel.

TABLE III

Mechanical Analyses for Experiment No. III

Diam. in mm.	A	1	2	3	4	5	6	7	8	9	10
2-1	5.0	0.2	13.2	33.4	0.0	1.6	18.1	3.6	8.2	6.8	5.2
1-½	35.6	23.9	58.1	55.4	8.1	22.3	40.4	43.6	51.7	37.2	38.1
¼	46.5	70.9	27.2	8.0	70.8	70.9	40.1	43.9	36.2	47.9	55.2
⅛	8.1	4.5	0.3	0.3	21.1	4.5	1.0	8.3	3.1	6.8	1.3
1/16	1.2	0.4	0.4	1.1	Tr	0.4	0.4	0.3	0.4	0.5	0.2
Pan	3.6	0.1	0.8	1.8	Tr	0.3	0.0	0.3	0.4	0.8	Tr
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

A. Average of six samples of source sand.
First run. Average volume and velocity, 5 minutes run to form bars.
1. Point of curve 1.
2. End of long bar below curve 1.
3. Below point of curve 2
Second run. Low volume, 15-minute period.
4. Bar at point of curve 1.
5. End of long bar below curve 1.
6. Below point of curve 2.
Third run. High volume, short period 5 minutes.
7. Point of curve 1.
8. End of long bar below curve 1.
9. Below point of curve 2.
10. At end of channel, near drain.

The first particles to come to rest at any of the sites of bar formation were the large 2-1 mm. grains. The bars continued to grow as more of these grains moved down the stream. As time elapsed it was noted that some of the large particles were carried out of the upstream bars and passed down to the next bar or continued farther downstream. At the same time the intermediate grades were moving from the source and covering the upper part of the original bar of coarse grains that remained upstream. Thus the final bar included a nucleus of coarse material covered with the finer grades. Comparison of analyses 1 and 3 illustrates clearly the result. Number 1, close to the source, had lost most of the 2-1 mm. grade and retained a large part of the 1-½ mm. grade but had an excess of the ½-¼ mm. grade. Sample number

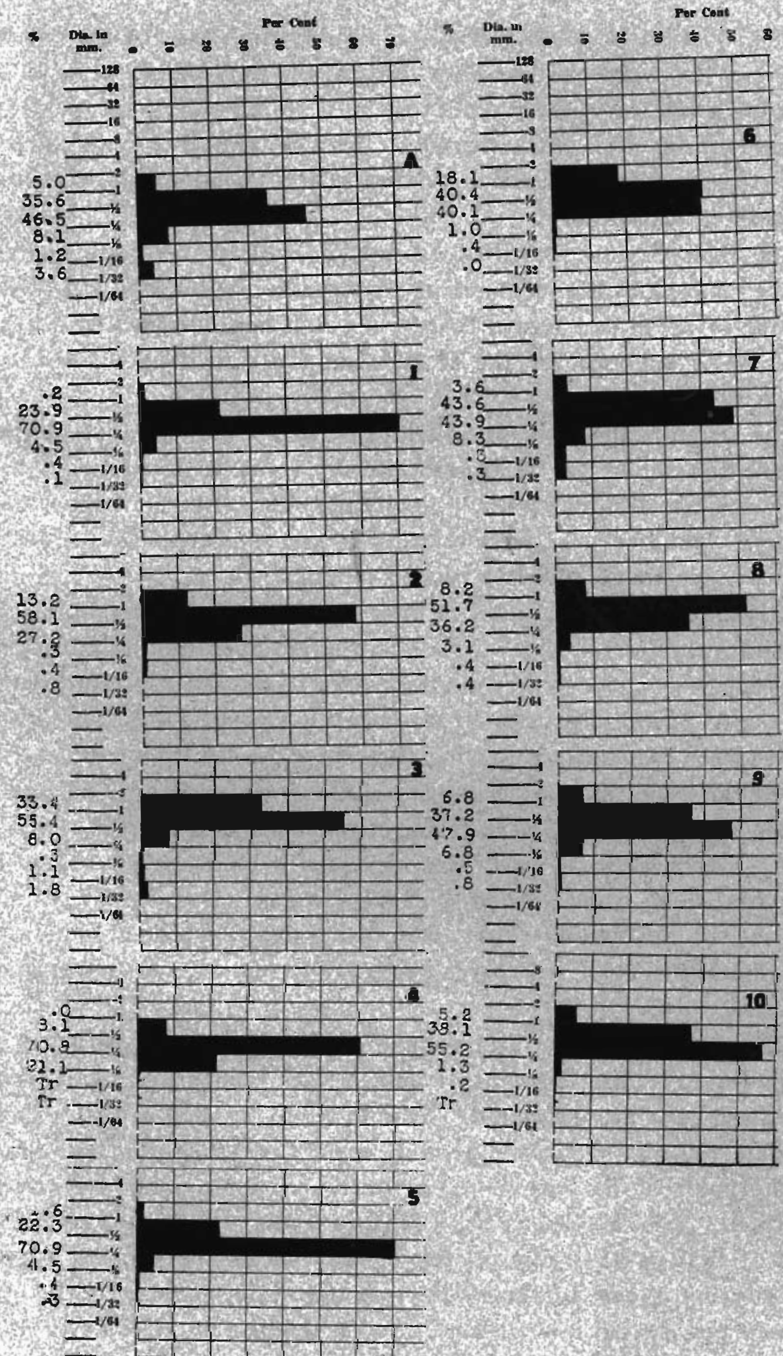

FIG. 44.—Mechanical analyses of deposits in Experiment III.

3, from just below curve 2, shows a high concentration of the coarsest grains of the source material, one-third of the total sample being of the 2-1 mm. grade, and 55 per cent in the 1-½ mm. grade, with very small amounts in the four smaller grades. Sample number 2 helps to check these statements as the analysis shows clearly an intermediate position between bars 1 and 3.

The channel was cleaned of all deposits and for a second run new source material of the same average composition was added. A stream volume of about one-fourth that of the first run described above was used. The analyses for the second run are shown in Table III as numbers 4, 5 and 6.

The action is almost identical with that of the first set-up, and direct observation shows the quick movement of the large particles, their early concentration in bars, and finally the slow advance of the smaller grains. All movements were retarded by the smaller volume of water, so the water was allowed to run 15 minutes.

It is important to note that in both set-ups no movement of fine silt or sand was observed beyond the bars where it appeared in the analysis. In other words, the writer was convinced that the concentration of the coarse grades downstream was not the result of the finer grades having been washed out, making the coarse grades lag materials.

The third run followed a complete cleaning of the channel and adding of new source materials of the same composition as used in the previous runs. The volume of water was increased to double that used in the first run. The results obtained in the third run were nearly identical to those of the former runs. A fourth sample, which also indicates the concentration of the coarse grades downstream, was taken in the last run.

The effect of velocity and volume of the water, or competency, on its power to transport grains of known sizes is indicated clearly when the three runs are compared. The first run, or that with the intermediate velocity, shows the greatest concentration of the large grades at the point of the second curve, or the farthest point downstream analyzed. The doubled velocity did not result in a greater concentration of the coarse grades, as might have been expected, but instead, caused a movement of the source material in almost exactly the same proportions present in the material fed at the source. The low velocity and volume did not cause a complete abandonment of the coarse load nor a large increase in the fine grades. Instead, there was an increase in the intermediate grades transported, and the movement of the coarse grades in greater proportions than contained in the parent sand was continued.

In a natural condition it is true that local contributions from tributary streams, bank erosion and slope wash may mask the range of materials which are being carried through from the headwaters or from the parts of the stream which are carrying the heavier loads. The material normally studied is the net result of all of these factors. When it is possible, however, to distinguish mineral or rock constituents and trace the source of these particles, then it may be possible to use the information gained from these experiments.

The "peanut" gravels of the Dakota stage of Montgomery county in southwestern Iowa and east of Louisville, Nebraska, along Platte river, contain vein quartz, quartzite and brown chert pebbles. The writer believes this material was derived from the land areas to the north and northeast in parts of Minnesota, Wisconsin and eastern Iowa, and that the streams at the time of deposition had their mouths relatively close to the places where the deposits are now exposed. The pebbles are all well worn and very few have prominent elements of angularity. The pebble beds do not represent fresh materials contributed as the result of short transportation from a newly uplifted area but are constituted of materials which have been carried through from a long distance and concentrated during transportation. The thicker beds are indicative of major accumulations from the principal or main channels. Where the gravels occur with lenses of finer materials, as at Coburg, Iowa, the competency of the stream probably was increased.

In making interpretations of mechanical analyses or of the textures of sands which have a concentration of coarse materials with the fines lacking or of small percentage, the statement is frequently made that the fine grades have been carried out and may be found farther from the source. The writer believes this statement may be true in some cases, but he believes also that there are cases where the fines may be found closer to the source, having not yet reached the site of deposition of the coarse sands.

The writer wishes to acknowledge the assistance given him in several

parts of these experiments by the students of the 1929 class in sedimentation laboratory work. After the above results were secured, several students continued the work and obtained corroborative results.

Appendix A

Laboratory Methods Used in the Analysis of Dakota Sands

The study of any stratigraphic sequence has for its purpose, even though it may be used commercially, the increase of knowledge concerning the rocks involved. Such an increase in knowledge will ultimately improve the character of the interpretations made concerning these rocks and, therefore, yield a truer picture of their history. To accomplish this end careful field observations must be made, and notes must be taken of minor details and variations of texture, cross-bedding, ripple marks, concretionary zones, gradations of cementation and any other prominent lithologic features. Also, it is now recognized that other features of the rocks are best understood after a complete analytical laboratory study. The degree of precision and completeness of this study may vary considerably to suit the problem. At the beginning of the study, when the possibilities are unknown or uncertain, the work should be thorough. One factor or set of analyses may yield results in one study while other sets of analyses may be more valuable in other work.

Sedimentary rocks have been given so little careful analytical attention that little is known of the true value of mechanical, mineral and shape analyses, contemporaneous structures, alterations and concentrations of minerals. An effort has been made in the previous chapters to interpret findings of that nature. When more analyses have been made and compared, with some experimental work to check the interpretations, with more observations on present day environments, such conclusions can be made and used with greater surety. For the present, it is well to make laboratory studies and record the observations for future interpretation or comparison with later work. The data should be obtained in a quantitative form to be of comparative value.

In the study of the Dakota rocks, both in the field and in the laboratory, the need for quantitative data has been recognized. To aid others in similar work the methods used by the writer in studying the Dakota rocks and now generally used in the sedimentation laboratory at the University of Iowa, and some of the steps in the procedure, are shown in outline form below. The outline is followed by a brief discussion of some of the methods.

Outline of Analytical Work

A. Sampling (Field)
   1. Single specimen } Vertical and horizontal
   2. Composite specimen }
   3. Notebook sketches and diagrams of textures, structures and relations to bedding
B. Splitting samples for analysis (Field and Lab.)
C. Preparation of samples (Laboratory)
   1. Crushing
      Clay, shale, silt, limestone
   2. Cleaning
      Ferruginous, clayey and dirty sands
   3. Freeing of cement
D. Mechanical analysis
   1. Inspection of sample
   2. Subsidation
   3. Sieving
      Screens
      Mechanical shaker
      Cleaning of screens
   4. Filing of separates
E. Mineral separation
   1. Selection of grades
   2. Electromagnet
   3. Heavy liquids
      Evaporating dish
      Separatory funnel
      Centrifuge
F. Mineral determinations
   1. Binocular microscope
      Sight recognition
      Microchemical tests
   2. Petrographic microscope
      Immersion in index of refraction liquids
      Determination of optical properties
      Reference to tables based on refraction index, birefringence, light-axis relation, optic sign, pleochroism, etc.
G. Shape analysis
   1. Comparative method
   2. Quantitative measurements
H. Plotting of results

DISCUSSION OF PROCEDURE

A. Field sampling.—The method of taking a sample differs somewhat according to the use and character of the specimen. As much of the material used in the study of the Dakota stage is well consolidated, a small hand specimen was taken from the most representative part of the exposure or a series of small chips was taken from various parts of the zone. Study of this type of material can best be made from a thin section.

When the material is of a friable, loosely cemented type, or is bound by limonitic iron oxide or calcite, small hand specimens containing two or three hundred grams, taken across the bedding or parallel with the bedding, are satisfactory. When a composite specimen is desired, the face of the exposure is cleaned with a hammer, and then the fresh face is cut down carefully, catching the rock fragments in a small hand scoop, care being taken to cut off the same amount of material for each unit of the vertical face. Usually it is good practice to take a large sample in this manner and then quarter it to the desired amount.

Of equal importance is the care given to the explanation of the position in the rock ledge from which each sample is taken. If a sample is taken from a single foreset zone or from a portion of a ripple zone or a mud crack filling or any such position, a brief sketch should accompany the sample so that accurate interpretations can be made from the mechanical analysis. In the case of composite samples the notes should indicate the nature of the bedding and texture of the zones included in the sample. Wentworth[155] gives other details and precautions for taking samples, methods of labelling and other miscellaneous information.

B. Splitting samples for analysis.—It is especially important that the specimen be carefully divided with a good type sample splitter, as any other method of choosing the right amount for analysis does not yield accurate data.[156]

C. Preparation of samples.—The majority of the samples of the Dakota stage which could be handled for a mechanical analysis contained so much of either clay or iron oxide that it was necessary to give them a thorough cleaning before making further studies. In the case of the friable sandstones and siltstones this cleaning was accomplished by washing in distilled water, or water condensed from the steam pipes of the University heating line. The washing process consists of boiling, deflocculating the clay by the use of sodium carbonate, shaking in a cylinder until thoroughly mixed and allowing the coarser grains to settle for a five minute period. The material left in suspension is then siphoned off and caught in a beaker. The sand in the cylinder and clay in the beaker are filtered separately, dried and screened. If the amount of clay and silt is less than 10 per cent it is

155 Wentworth, C. K., Methods of Mechanical Analysis of Sediments: Univ. Iowa Studies in Nat. Hist., Vol. 11, No. 11, N. S. 117, pp. 9-17, 1926.
156 Wentworth, Idem, pp. 18-20.

not separated further but shown in the analysis as the minus 1/32 mm. grade.

The ferruginous sands had to be treated with acid before any type of mechanical separation could be used. The common procedure is to use a 15 to 18 per cent hydrochloric acid solution with about 10 per cent of dilute stannous chloride. This is very effective in removing the iron oxide. Some of the ferrous iron goes into solution in the dilute acid and can be washed out or filtered. Usually the balance of the iron oxide remains as a feathery flocculent. When the specimen is free of acid this material can be put in suspension by adding sodium carbonate. The material is then siphoned and the residue remaining in the bottom of the cylinder is filtered, dried and analyzed. A clean white sand results. This method has been used with practically all of the sands of the Dakota that have been analyzed as there are very few which do not contain iron oxide.

The few specimens cemented by calcite were dissolved in a dilute hydrochloric acid, washed free of the acid, filtered, dried and analyzed.

D. Mechanical analysis.—The procedure followed is similar to that described by Wentworth[157] but with several modifications to fit the particular samples. A mechanical shaker was used and each sample was given a ten minute period of shaking. Considerable care was exercised in cleaning the screens after each analysis, and two sets of six inch calibrated screens were used for this particular work. The clean sands, freed of iron oxide, clay, or other adhering materials, will pass through the sieve with less material sticking in the mesh.

The method of subsidation used by the writer differs somewhat from the method of elutriation described by Wentworth.[158] Directions for analysis by subsidation are given below.

A. Preparation of specimen
   1. Crush carefully to a practical size, without breaking the granular particles. Roll with light metal roll on glass plate.
   2. Weigh carefully on triple beam balance to 0.01 gram; 10 to 15 grams of clay, shale, loess, or silt is ample; limestone or other soluble samples demand 40 to 50 grams to provide a sufficient residue for analysis.
   3. If materials are calcareous and the percentage of soluble material is desired, treat a small weighed part of the specimen with HCl; boil slowly for 3 to 5 minutes, or until solution ceases. Filter after moderate cooling.
   4. Mix specimen (not acid treated) with distilled water and heat slowly; if the clay does not stay in suspension on cooling, add one-half to one gram sodium carbonate to aid deflocculation, then heat slowly until all but coarse grades are in suspension. Allow to cool to room temperature.

157 Wentworth, Idem, pp. 20-35, 39-43.
158 Idem, p. 39.

B. Separation by settling

1. Pour prepared material into graduated cylinder and fill latter with distilled water to height of 15½ inches.
2. By closing open end of cylinder with palm of hand, shake the liquid well, seeing that the sediment is well toward top. Set on table and allow to settle without agitation for *5 minutes.* Time with a stop watch.
3. Insert siphon tube carefully and start siphon action at expiration of the 5-minute period. Collect the liquid thus siphoned in a 1,000 cc. beaker with a depth of 5½ inches to 5¾ inches. (See 7.)
4. After a gentle agitation of liquid obtained in (3) allow it to settle *5 minutes,* again using stop watch for timing.
5. At end of five-minute period noted in (4) siphon carefully with a five-inch glass siphon tube into another 1,000 cc. beaker. This liquid just siphoned is allowed to settle 15 minutes.
6. Siphon into sink the liquid obtained in (5) at end of 15 minutes.
7. After completing (3) the residue in the cylinder should be washed again with distilled water by filling to 15½-inch level, shaking and allowing to settle.
8. The operation in (7) starts a new series usually called the "second period" which is simply a repetition of the steps outlined in 3, 4, 5 and 6.
9. Repeat to third period of settling, and if liquid in the 15½-inch column does not clear immediately after shaking in third period continue to fourth or more periods as deemed necessary.
10. Weigh to nearest 0.01 and label completely, filter papers to receive the various fractions at end of settling.
11. Wash final settling products into respective filter papers.
12. After complete filtering, place filter paper with residue in oven to dry. After 2 or 3 hours drying at 80 to 90 degrees C. remove from oven and allow to cool on protected shelf. Then weigh to 0.01 gram on laboratory balances. Subtract weight of filter paper from gross weight to get net weight of each grade.

SUPPLEMENTARY NOTES:

A. Cautions (Referring to numbers above)

(A1) In the case of a fine-grained sediment much care must be exercised to prevent fracturing grains. If possible break with fingers or allow to stand in water over night to aid separation. In some cases, e. g., a ferruginous sandstone, the specimen must be boiled in acid to perfect granular disintegration.

(A2) Usually a smaller amount of fine materials will suffice. However, be careful the coarse grade does not fill the bottom of the cylinder to the level of the siphon tube.

(A3) If it is necessary to use the acid-treated sample for settling analysis be sure to wash out all the acid during the first filtering process.

(A4) Use a small quantity of sodium carbonate. An excess may cause a reversal of action. If the liquid is too warm convection currents may prevent settling of particles desired.

(B3) Be careful of time periods. Do not undertime. If the period is allowed to run overtime, the error may be corrected by washing and siphoning another period. An error of undertiming cannot be readily corrected. Use care that end of siphon does not disturb the sediment in the bottom of the cylinder.

B. Results

(a) The sediment which remains in the bottom of the cylinder after the numerous periods of washing has a settling rate of 15 inches in 5 minutes or faster. This comprises the materials 1/32 mm. and larger in diameter.

(b) The material which settles to the bottom of the first beaker (See B3 above) has a settling rate of 5 inches in 5 minutes or just ⅓ that in the tall cylinder. This beaker contains the 1/64 mm. grade.

(c) The second beaker containing the siphoned product of (b) has a water column of 5 inches, hence a settling period of 15 minutes is necessary. The sediment which is retained in bottom of beaker is the 1/128 mm. grade.
(d) The liquid siphoned to the sink in the last process represents everything smaller than the 1/128 mm. grade. The quantity of this grade is determined by difference.
(e) Frequently the analysis is carried only to the second grade; that is, the 1/128 mm. grade is not determined, but lumped with all other fine grades. This depends on the ease with which separation of particles and deflocculation is attained and the importance or abundance of the finer grades.

The settling ratio of 3 is nearly constant for the range between 1/16 and 1/128 mm. Below or above these sizes the ratio may vary. According to Stokes' law, small particles fall in a column of water with velocities proportional to the square of their diameter. Experiments with various distances of settling and microscope measurements of the different separates has shown that the particles which settle 5 inches in 5 minutes are almost exactly one-half the diameter of those which settle 15 inches in 5 minutes. The same ratios appear to hold for a third smaller grade. It is true that careful work is essential to hold the grain sizes within the limits of the grades desired.

E. Mineral separation.—1. Electromagnetic separation

The sands of the Dakota stage contain very little magnetite or other moderately magnetic minerals. Attempts have been made to separate the minerals contained in these sands by the use of a strong electromagnet. A magnetic separator based on the principle of the Dings wet separator was designed by the writer and made at the University of Iowa and serves satisfactorily for the average separation. The sand is placed in a long tube filled with water. This tube is set between the pole pieces of the magnet and moved back and forth along the axis of the tube to agitate the water and to keep the grains free. With varying amounts of electric current different minerals are held against the glass of the tube. The writer has not yet been able to calibrate the instrument other than to effect separations of magnetite, ilmenite and glauconite from the other minerals in the sand.

The electromagnetic separator may be used in conjunction with a calibrated tube, such as a quantitative centrifuge tube, to determine the volume of magnetic substances in a loose sand or crushed sample. Johnson[159] applied this method to determine the amount of casing scale in well cuttings, which in turn aided in correlation of water zones.

2. Heavy liquid separation

159 Johnson, H. L., Correlation of Five Oil Wells in Texas; Univ. of Texas Bull. 3001, pp. 139-147, 1930; and unpublished thesis, Univ. of Iowa, p. 6, 1930.

Many writers have described the use of the ordinary separatory funnel in making mineral separations in liquids of high density. This method is satisfactory for grains ranging in sizes between 1 mm. and ¼ mm. For larger grains and in some cases with grains as small as ⅛ mm. an ordinary two inch porcelain evaporating dish can be used satisfactorily. The dry grains are placed in the dish, which is then half filled with bromoform or any other heavy liquid to be used. Usually it is sufficient that the dish be half full of the liquid, but a larger amount of the liquid makes it possible to pour off the floating grains with greater ease. With the liquid in the dish a small amount of agitation such as a whirling motion of the dish mixes the grains sufficiently and will usually free any adhering grains. When the operator is satisfied with the separation the light or floating minerals are poured into a filter paper and the bromoform is caught in a container below. This bromoform can be used many times as it is not necessary to dilute it with a washing liquid. The heavy minerals which sink to the bottom of the evaporating dish and are now free of all but a few drops of bromoform are washed to a clean filter paper. Distilled water or benzol is usually used for this washing process and is caught below the filter paper in a bottle and saved for distillation.

To separate grains of dimensions smaller than ⅛ mm. the evaporating dish or separatory funnel does not yield the best results, as there is too great a tendency for the grains to stick together. The small amount of moisture on the grains or the water in the bromoform prevents a complete disaggregation of the small grains. In order to prevent such an occurrence the grains should be dried thoroughly and the bromoform carefully distilled to drive off all moisture. A clean separation of heavy and light minerals can be obtained by using a centrifuge. In the laboratory at the University of Iowa a Bausch and Lomb electric centrifuge with guard has been used successfully. The centrifuge can be used for the separation of coarser grains, but as it takes more time than the evaporating dish method, and as the grains do not adhere as firmly in the larger grades, the method is seldom used. It is possible, however, to determine the quantity of heavy minerals directly by using a calibrated centrifuge tube.

Brown[160] has described the use of the centrifuge in making separations of the heavy minerals of soils. Brown found that by using a

[160] Brown, I. C., Jour. Paleo., Vol. 3, No. 4, pp. 412-414, Dec., 1929.

small glass capsule fused to the end of an ordinary centrifuge tube he could make a very clean separation of light and heavy minerals in bromoform and at the same time recover the grains without contamination and the loss of bromoform and could thus make quantitative determination of the heavy minerals present in the soil. This method was worked out in the sedimentation laboratory at the University of Iowa under the direction of the writer. It has been necessary in only two or three cases to use this method in separating the heavy minerals of the Dakota samples.

F. Mineral determinations.—The usual methods for determining minerals have been followed in the present study. It is only after considerable practice and accumulated knowledge that it is possible to make accurate determination of minerals in a sedimentary rock by the use of the binocular microscope alone. It is impossible to differentiate the various species of feldspars, amphiboles and pyroxenes, or to recognize grains of quartzite and many other clear or glassy types. In general the writer prefers to use a petrographic microscope to study the minerals of a rock as individual grains or in thin section.

A common practice is to take the separate of minerals obtained from a heavy liquid separation and study them with a binocular microscope. Minerals which occur in large proportions in the separate are segregated and several grains of each are placed in a small shell vial or gelatine capsule. After all of the prominent species have been sampled in this manner, the work is transferred to the petrographic microscope. Several grains are selected from one of the vials and subjected to a critical study. The grains are crushed, if necessary, and immersed in an index of refraction liquid of known value. This is continued until the limits of the indices are known; experience reduces these trials to a minimum. At the same time that the indices are being determined it is possible to note many of the optical properties of the mineral. With these facts it is possible to trace the mineral to its proper classification. The index of refraction liquids used in the University of Iowa laboratory are described by Emmons.[161] This method of mineral determination yields the best and most reliable results.

G. Shape analysis.—It is generally supposed that the shapes and surface features of the constituent grains of a sandstone aid in the

161 Emmons, R. C., Amer. Min., Vol. 13, pp. 514-515, 1928.

recognition of the environment of deposition. More stress has been placed on this criterion than the writer feels is justified. It seems possible that grains of similar shape or surface characteristics are deposited by different agents in environments of a wide range. However, in order to make the study of the sediments complete the writer feels that it is desirable to make the shape determinations.

The majority of the workers have established schemes of their own and describe the grains as "rounded," "well-rounded," "subround," "subangular," "angular," and various modifications of these terms. They have no accurate quantitative basis for classifying the shapes into these groups, and it is very difficult to evaluate or to compare the work of different investigators. Some workers select grains of different shapes, mount them, and use them throughout their particular problem to compare with the grains of the various samples of their studies. This is satisfactory from their point of view, and in most cases the determinations made by the individuals are true to their standards. A good illustration of this method may be had in the work of Trowbridge and Mortimore.[162] Undoubtedly, the grains classified as "round" by these authors would compare closely with photographs of round grains. However, another worker who has a different conception of round grains might call such grains "subround." The application is of more importance when one is dealing with grains which have some fresh surfaces and edges but yet have undergone sufficient abrasion to wear the most prominent surfaces and corners. Few attempts have been made to measure the amount of abrasion of sand grains and then express the results in a numerical value so that any stated value would fall in its proper place. Arbitrary divisions placed in these numerical values would give the basis for the use of such terms as "round," "subangular," etc.

In 1927 Cox[163] discussed this problem and decided that it is possible to make a determination from sand grains which will yield quantitative measurements. He bases his determinations upon the ratio of the area of a cross section of a grain to the area of a circle which has the same circumference as the perimeter of the measured grain. It is obvious that a grain with a large number of sides and with nearly equal radii, when seen in cross section, will yield a ratio approximating that of a circle with the same perimeter. Even a square,

[162] Trowbridge and Mortimore, Econ. Geol., Vol. 20, pp. 409-423, 1925.
[163] Cox, E. P., Jour. Paleo., Vol. 1, pp. 179-183, 1927.

or a cube when considered as a three dimensional body, will yield a ratio of over 78 per cent, while an isosceles triangle will yield a ratio of 54 per cent. The writer believes that such ratios are misleading, as the cube or pyramid may be fresh and have suffered very little wear. He believes that any standard of the measurements of shapes of grains should be based upon the relative amount of wear on the grain. This means, of course, that some postulate must be made of the original shape of the grain prior to its abrasion.

The writer devised a method by which the shape of grains could be measured and expressed in quantitative terms.[164] The basis or fundamental on which such determinations and interpretations should be based is the amount of wear or abrasion that has affected any given grain. This can be called the factor of wear.

Wentworth[165] bases his considerations and measurements of pebbles and cobbles on a similar principle and expresses it as the roundness or (and) flatness ratio. A sand grain has fewer developed[166] facets than pebbles. Cox[167] avoids the ratio of wear as a basis of measurement and uses the ratio of areas of the grain at the *time of measurement* as compared with a theoretical area the grain would have if its cross section were a circle of the same perimeter. This might be called dealing in futures as it attempts to evaluate the abrasion to be accomplished if a perfect sphere results rather than what has already been done.

The writer is convinced by his observations on the shapes of pebbles and sand grains, gained from field and laboratory studies, that the original shape of the rock or grain when it is first subjected to abrasion is a primary control on the ultimate shape. In addition to this the composition and structure of the fragment sometimes influences the place and rate of abrasion. The nature of the abrading agent is a factor of unknown value and may be a greater influence in the ultimate shape of a pebble in one set of conditions, while in another environment the same agent may have little effect.

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164 Tester, A. C., Measurement of Shapes of Rock Particles: Jour. Sed. Petrology, Vol. 1, No. 1, May, 1931, pp. 3-11.

165 Wentworth, Jour. Geol., Vol. 27, pp. 507-521, 1919; and U. S. G. S. Bull. 730c, p. 93, 1922.

166 Wentworth, Bull. 730c, p. 93.

167 Cox, op. cit., p. 181.

Appendix B

Bibliography

The bibliography is divided into two parts; part one includes the publications which make a specific reference to the type area of the Dakota stage or which aided in the earliest studies of the region; part two contains the general articles on the Dakota in other localities, articles pertaining to methods, procedure, paleontology, and general principles.

In this bibliography an attempt has been made to bring together a complete list of articles which make a contribution to the knowledge of the rocks of the Dakota stage in northeastern Nebraska and adjacent Iowa, the type area. Many articles which make only a passing reference to the Dakota section have been excluded. Articles which use the Dakota sections of previous writers or have used conclusions found elsewhere have for the main been omitted.

Practically all of the articles included in the first part of the bibliography have been reviewed by the writer, even though no reference is made to these articles in the historical summary. The publications cited in part two contain material used in the present writing or have been consulted for comparative purposes or are generally familiar to the writer.

The chronological arrangement of part one is used for ready reference and as a general guide to the development of the studies and knowledge of the Dakota stage. Part two is arranged alphabetically by authors. The numbering of the references is consecutive through both parts.

PART I

ARTICLES RELATING TO TYPE AREA OF DAKOTA STAGE

1804

1. Thwaites, Reuben Gold, editor Original Journals of Lewis & Clark, 1804-1806, in 7 vols. Dodd, Mead & Co., New York, 1904.
(Note: With the exception of reference No. 2 the bibliography does not contain references to a large number of publications made by members of the Lewis & Clark party or by other persons who claimed access to the original records. Some of the publications are known to be spurious, while others are based on partial data or on badly edited and abridged notes. The edition by Thwaites contains all the original diaries, unpurged, including those of Gass, Floyd and other subordinates.)
2. Allen, Paul, and Biddle, N. (editors), History of the expedition under the command of Captains Lewis and Clark to the sources of the Missouri;

thence across the Rocky Mountains and down the river Columbia to the Pacific Ocean performed during the years 1804-1806. Two vols., 470 pp. and 522 pp., maps, etc. Philadelphia, 1814. See pp. 49-51.

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6. Nuttall, Thomas, Geological Structure of the Valley of the Mississippi: Phila. Acad. Nat. Sci. Jour., Vol. 2, pp. 14-52, 1821.

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7. James, E., Account of Expedition from Pittsburg to the Rocky Mountains performed in 1819-1820, under the command of S. H. Long. Description of fossils by Thomas Say, Vol. 1, p. 106, and Vol. 2, pp. 410-411, Philadelphia, 1823.

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11. Morton, S. G., same title as above: Amer. Jour. Sci., Ser. 1, Vol. 18, pp. 243-250, ills., 1830.

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12. Morton, S. G., same title as above: Amer. Jour. Sci., Ser. 1, Vol. 23, pp. 288-294, ills., 1833.
13. Morton, S. G., same title as above: Amer. Jour. Sci., Ser. 1, Vol. 24, pp. 128-132, 1833.

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14. Nicollet, J. N., On the Geology of the Region on the Upper Mississippi and the Cretaceous Formation of the Upper Missouri: Amer. Jour. Sci.,

Ser. 1, Vol. 41, pp. 180-182, 1841. See also Assoc. Amer. Geog. Rep., pp. 32-34, 1843.

15. Nicollet, J. N., On the Cretaceous Formation of the Missouri River (with discussion): Amer. Jour. Sci., Ser. 1, Vol. 45, pp. 153-159, abstr., 1843.

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16. Owen, D. D., Geological Survey of Wisconsin, Iowa and Minnesota, and Incidentally a Portion of Nebraska Territory; made under direction of U. S. Treasury Dept.: Phila., 1852, p. 195.

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17. Marcou, J., Resume Explicatif d'une Carte Geologique des Etats-Unis et des Provinces Anglaises de l'Amerique du Nord, etc.: Bull. de la Soc. Geol. de France, 2 Ser., Vol. 12, pp. 813-936, map, 1855.

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18. Hall, James, and Meek, F. B., Descriptions of New Species of Fossils from the Cretaceous Formations of Nebraska: Am. Acad. Arts, Mem., N. S., Vol. 5, pp. 379-411, 1856.

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20. Meek, F. B., and Hayden, F. V., Descriptions of New Fossil Species of Mollusca Collected by Dr. F. V. Hayden in Nebraska Territory: together with a complete catalogue of all remains of invertebrata hitherto described and identified from the Cretaceous and Tertiary formations of that region: Phila. Acad. Nat. Sci. Proc., Vol. 8, 1856, pp. 265-286, 1857.

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DESCRIPTION OF PLATE III

FIGURE A. Photomicrograph, zone 6a, Section 1, ⅛-1/16 mm. grade. Shows rounded zircon grain, mica, and a frosted quartz grain. Mag. 80x in 1.742 index liquid. Magnifications approximate.

Zone 6a, Section 1, Sioux City shale pit, marine fossiliferous bed of Dakota stage.

FIGURE B. Photomicrograph, zone 6a, Section 1, ¼-⅛ mm. grade. Shows surface etching on quartz grain and grain of microcline. Mag. 100x.

FIGURE C. Photomicrograph, zone 6a, Section 1. Shows glauconite grains. X-nicols, Mag. 200x.

FIGURE D. Photomicrograph, zone 6a, Section 1. Shows fresh plagioclase feldspar in iron oxide cement. X-nicols, Mag. 200x.

FIGURE E. Photomicrograph, zone 6a, Section 1. Shows fresh feldspars and quartzite grains in silt matrix. X-nicols, Mag. 200x.

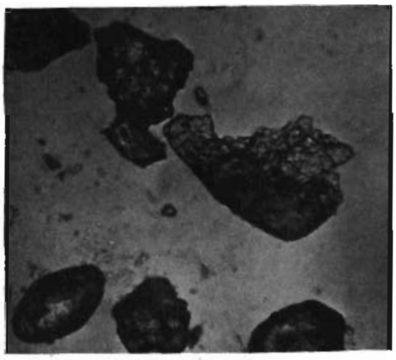
FIGURE F. Photomicrograph, zone 6a, Section 1. Shows large rounded grain of quartzite and fresh feldspars in fine calcite matrix. X-nicols, Mag. 200x.

FIGURE G. Photomicrograph, zone 9, Section 1. Graneros sandstone. Shows spine and quartz grains in calcite matrix. X-nicols.

FIGURE H. Photomicrograph, zone 6a, Section 1. Shows basic feldspar alteration to calcite and quartz. X-nicols, Mag. 200x.

FIGURE I. Photomicrograph, zone 6a, Section 1. Shows feldspar alteration. X-nicols, Mag. 200x.

FIGURE J. Photomicrograph, zone 12, Section 3. Shows glauconite in center with small rhombic crystals of calcite.



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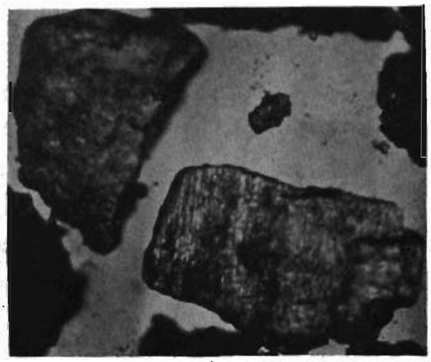

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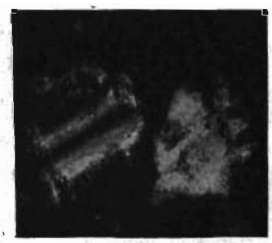

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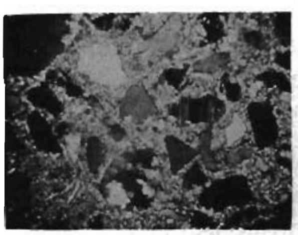

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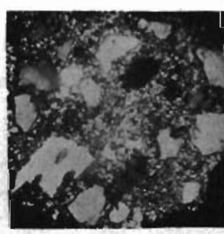

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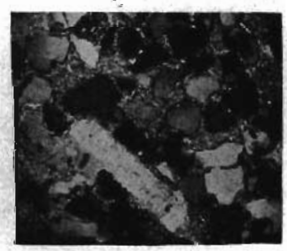

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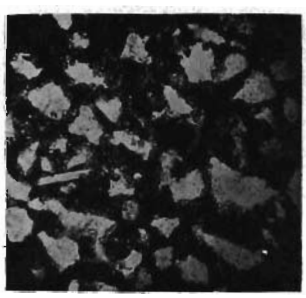

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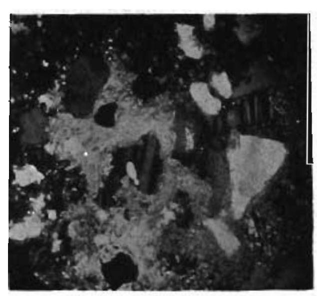

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DESCRIPTION OF PLATE IV

FIGURE A. Photomicrograph, zone 1, Section 6. Shows grain of glauconite in center. X-nicols, Mag. 200x.

FIGURE B. Photomicrograph, zone 8, Section 7. Shows much glauconite and pyrite in matrix of calcite. Polarizer only.

FIGURE C. Photomicrograph, zone 8, Section 7. Shows glauconite. X-nicols.

FIGURE D. Photomicrograph, zone 4, Section 7. Shows glauconite grain in circle near center of field. 1/8-1/16 mm. grade in 1.742 index liquid.

FIGURE E. Photomicrograph, Section 9. Shows texture and shape of particles. X-nicols, Mag. 80x.

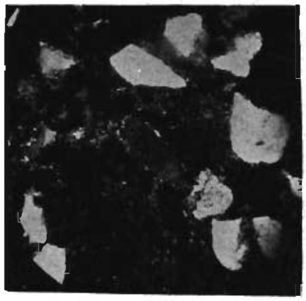
FIGURE F. Photomicrograph, Section 8. Shows triangular shaped large grain of chert (upper center). Mag. 84x.

FIGURE G. Photomicrograph, zone 4, Section 10, 1/4-1/8 mm. grade. Shows sub-round grain in center and a large number of curvilinear grains of quartz. In 1.742 index liquid. Mag. 84x.

FIGURE H. Photomicrograph, zone 3, Section 10, 1/4-1/8 mm. grade. Shows curvilinear grains of quartz with surface etching. In 1.742 index liquid. Mag. 84x.

FIGURE I. Photomicrograph, zone 1, Section 10, 1/4-1/8 mm. grade. Shows curvilinear and subangular quartz grains with surface etching. In 1.742 index liquid. Mag. 74x.

FIGURE J. Photomicrograph, zone 1, Section 10, 1/4-1/8 mm. grade. Shows typical curvilinear quartz grain in center. In 1.742 index liquid. Mag. 84x.



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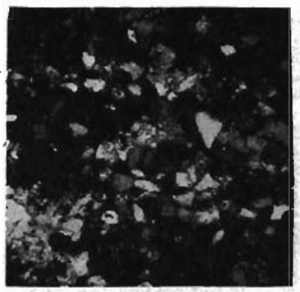

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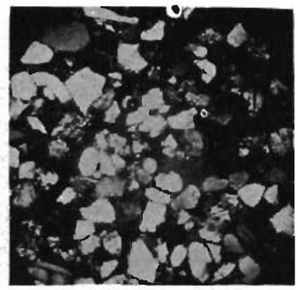

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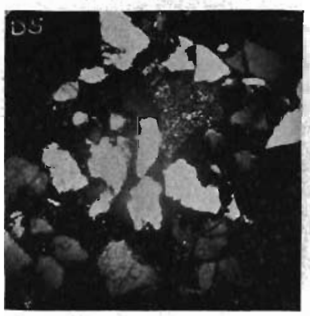

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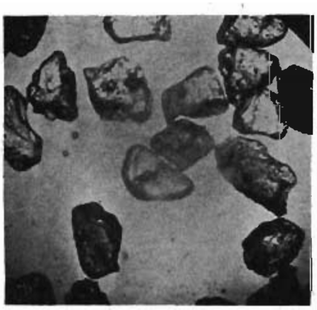

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THE STRATIGRAPHY OF THE KINDERHOOK SERIES OF IOWA

BY

LOWELL ROBERT LAUDON

CONTENTS

LIST OF ILLUSTRATIONS

THE KINDERHOOK SERIES OF IOWA

INTRODUCTION

The Mississippian of Iowa is represented only by four series of formations. Three series of these Mississippian formations, the Kinderhook, the Osage and the Meramec, are well developed in the state while the Chester series is represented by only a single formation. Of these four series this paper deals particularly with the oldest or the Kinderhook.

The Mississippian of Iowa is of marine origin with limestone predominating. Dolomites, shales and sandstones are present but are of lesser importance. The Mississippian limestones are particularly noted for the great amount of chert which they usually contain. These marine sedimentary beds are almost without exception fossiliferous and usually carry a very prolific fauna.

The regional dip of the sedimentary strata in Iowa is to the southwest at a slope of about 12 feet to the mile. This dip brings the Mississippian rocks to the surface in a narrow belt extending across the state in a northwest-southeast direction. This belt of outcrop reaches from Keokuk on the southeast to Humboldt county in the northern central part of the state. The Mississippian strata are covered by younger formations to the west of Humboldt county.

Classification

The rocks that are now known as Mississippian were classed under various names, such as "Carboniferous," "Lower Carboniferous" and "Sub-Carboniferous," for a period of 70 years. This period lasted from 1821, when Thomas Nuttall[1] compared the "Encrinital group at Burlington" with the Mountain Limestone of Europe, until 1891 when H. S. Williams[2] proposed the term Mississippian for them.

In 1839 D. D. Owen introduced the term Sub-Carboniferous for the strata underlying the "Coal Measures" and overlying the Hamilton. M. DeVerneuil in 1847 recognized the fact that the Waverly group of Ohio definitely belonged with the Carboniferous. The St. Louis lime-

1 Nuttall, T., Observations on Geological Structure of the Valley of the Mississippi: Jour. Acad. Nat. Sci. Philadelphia, Vol. II, pp. 14-52, 1821.
2 Williams, H. S., Correlation Papers of Devonian and Carboniferous: Bulletin 80, U. S. G. S., p. 135, 1891.

stone was named by H. King in 1851. The final report of D. D. Owen on the geology of Iowa, Minnesota, and Wisconsin was published in 1852. In this report the Sub-Carboniferous was divided into a lower and an upper series. The division between these two series was at the base of the geodiferous bed or the center of what is now the Warsaw formation.

In 1853 Swallow correlated the Chouteau limestone, the Vermicular sandstone and the Lithographic limestone with the Chemung of New York. James Hall, working in Iowa in a period from 1856 to 1859, also referred these beds to the Chemung. In the same period Hall proposed the term Burlington for the "Encrinital group" of Owen and also cleared up the use of the term Keokuk. In 1860 C. A. White questioned the correlation of these beds with the Chemung, calling attention to the fact that the faunas were much like those of the overlying Sub-Carboniferous beds. Later in the same year, however, White and Whitfield recognized the "Chemung" of the Mississippi valley. It was in 1861 that Meek and Worthen realized that these beds were distinctly younger than the Chemung of New York and proposed the name Kinderhook for them. The Kinderhook of Meek and Worthen included only the Lithographic limestone (Louisiana), the Vermicular sandstone (Hannibal) and the Chouteau limestone. In 1874 C. C. Broadhead proposed the term "Chouteau Group" for the members included in the Kinderhook of Meek and Worthen. This term was not used, however, because the term Kinderhook held priority.

The Kinderhook has since been modified by Weller, Van Tuyl, and Moore to include certain of the shale beds below the Louisiana limestone and overlying the Devonian limestones.

Purpose of the Investigation

This investigation has been carried on with these points in view—to determine the stratigraphic relations of the Kinderhook strata within the series itself and with the overlying and underlying formations; to establish definite life zones that may be traced throughout the region; and to make correlations with adjacent regions based on the stratigraphy and paleontology.

Location of Area

The belt of outcrop of the Kinderhook of Iowa reaches roughly from Fort Madison on the southeast to the northern part of Franklin

TABLE I

Classification of the Mississippian Formations of the Mississippi Valley

System	Series	Formation
Mississippian	Upper Chester	Kinkaid Degonia Clore Palestine Menard Waltersburg Vienna Tar Springs
	Middle Chester	Glen Dean Hardinsburg Golconda Cypress
	Lower Chester	Paint Creek Yankeetown Renault Aux Vases Ste. Genevieve
	Meramec	St. Louis Spergen
	Osage	Warsaw Keokuk Burlington Fern Glen
	Kinderhook	Chouteau Hannibal Louisiana Chattanooga

county in north-central Iowa. This area of outcrop of the Kinderhook strata will be divided in this paper roughly into two provinces. The *southeastern Iowa province will include* all Kinderhook strata

TABLE II

General Classification of the Mississippian of Iowa

System	Series	Formation
Mississippian	Chester	Pella
	Meramec	St. Louis Spergen
	Osage	Warsaw Keokuk Burlington
	Kinderhook	Hampton English River Maple Mill

exposed in Des Moines, Louisa, Washington, Johnson and Iowa counties. The *north-central Iowa province includes* the Kinderhook of Tama, Marshall, Grundy, Hardin, Butler and Franklin counties. The section of Kinderhook strata exposed along Iowa river near LeGrand is located within the limits of the north-central Iowa province. However, these exposures are approximately midway between the best development of the Kinderhook in southeastern Iowa and the best development of the Kinderhook in north-central Iowa, so a special chapter will be devoted to the discussion of the LeGrand section.

Previous Work

The early work on the Kinderhook of Iowa has been partly reviewed in the history of the classification of the Mississippian. The work of Meek and Worthen while they were connected with the Illinois State Survey cannot be underestimated. Meek and Worthen, Hall, White, Swallow, Miller and Gurley, Shumard, and Winchell all figured very prominently in the description of Kinderhook fossils. More recently Charles Wachsmuth and Frank Springer, Stuart Weller, and R. C. Moore have described many species from the Kinderhook beds.

The county survey reports of Charles R. Keyes for Des Moines county, J. A. Udden for Louisa county, Samuel Calvin for Johnson county, S. W. Stookey for Iowa county, H. F. Bain for Washington county, T. E. Savage for Tama county, S. W. Beyer for Hardin and Marshall counties, M. F. Arey for Grundy and Butler counties, and I. A. Williams for Franklin county were all used very extensively.

The Kinderhook faunal studies of Stuart Weller from 1899 to 1906 have proven to be very valuable. Monograph I of the Illinois State Survey (Mississippian Brachiopoda) must also be mentioned.

F. M. Van Tuyl spent a series of summers studying the Mississippian of Iowa. The results of this field work were published in volume XXX of the Iowa Geological Survey. This report on "The Stratigraphy of the Mississippian Formations of Iowa" has been a constant reference book.

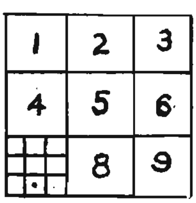
In 1928 the Missouri Bureau of Geology and Mines published a report on the "Early Mississippian Formations of Missouri" by R. C. Moore. This report forms a basis for many of the correlations made in this paper.

Field Methods

The field work upon which this report is based was carried on during the summer field seasons of 1928 and 1929. An attempt was made during this time to see every exposure of the Kinderhook within the state. These exposures have been mapped over a considerable part of the north-central Iowa province.

A great deal of the correlation has been done by zone stratigraphy. A zone is established by a combination of several factors. The association of species within a limited vertical distance is an important factor. The abundance of certain species and the scarcity of others is used very advantageously. The lithology of the beds often helps greatly in the establishment of a zone. Relatively barren horizons often form natural breaks between the zones. A combination of all of these factors will usually establish a zone that may be traced over considerable distances. During this work definite zones have been established within each of the members.

In this report positions within sections are located in the following manner. The section in which the position is to be located is divided into nine equal rectangles. These rectangles are numbered from left to right up to nine. The point to be located would then lie within one of these rectangles. This one would again be divided into nine equal rectangles and numbered accordingly. The position would then be within one of these smaller rectangles. If the position should lie within the seventh small rectangle of the fifth large rectangle its position would be 57. The small rectangle could be divided again and even a fourth time if the location of the point should demand such accuracy.



The position of the point in the diagram would be 78 of section —, R. — W., Twp. — N. If the smaller rectangle should again be divided into nine rectangles the position of the point would be 785 of section —, R. — W., Twp. — N.

A topographic base map was not available for the region and locations were made with the aid of county maps furnished by the State Highway Department. During the early part of the investigation the areal geology maps of the county survey reports were used extensively.

Nomenclature

The term Hampton is proposed for the Kinderhook beds of Iowa that lie stratigraphically above the English River formation and below the oldest beds of the Osage series. This formation is named for Hampton, the county seat of Franklin county, around which town this formation is best exposed.

The term North Hill is proposed for the oldest member of the Hampton formation in the southeastern Iowa province. This member includes all Kinderhook strata stratigraphically above the English River formation and below the brown dolomites of the Wassonville member of the Hampton formation. It is named for the exposure on North Hill in the city of Burlington, where the member with both its upper and lower contacts is exposed.

The term Kinderhook is used as a series name in this report and the terms Maple Mill, English River and Hampton are considered as formation names. If further classification is necessary the formations are divided into members and the members into zones.

The Hampton formation is divided in north-central Iowa into four members. The names Chapin, Maynes Creek, Eagle City and Iowa Falls were introduced by Van Tuyl in 1922 for these members and are retained in this report essentially as defined by Van Tuyl except for some slight changes in their contacts.

General Introduction to the Formations Involved in the Discussion

S. E. P.—Southeastern Province
N. C. P.—North-Central Province

The Cedar Valley limestone, S. E. P.—The Cedar Valley limestone unconformably underlies the Sweetland Creek beds of the southeastern province. It also underlies the Sheffield formation in the southeastern part of the north-central province. At other places in the north-central province it underlies different formations of the Lime Creek series. Lithologically it consists of hard gray fossiliferous limestone ledges and brown shaly dolomite. It is Upper Devonian in age.

The Shell Rock formation, N. C. P.—The Shell Rock formation unconformably overlies the Cedar Valley limestone and in the northern part of the north-central province is unconformably overlain by the Juniper Hill shale. In the southern part of the north-central province

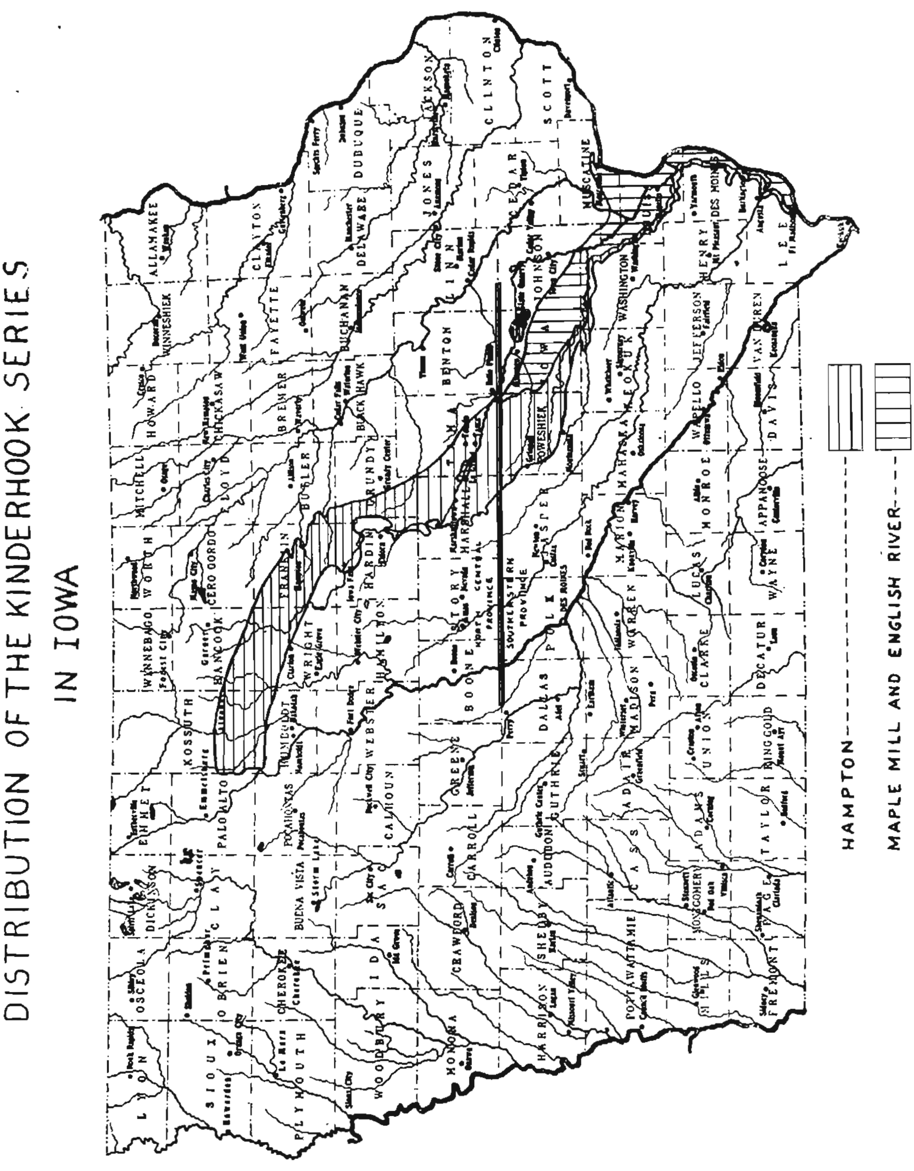


FIG. 45.—Map of Iowa showing distribution of the Kinderhook series in Iowa.

it is undoubtedly directly overlain by the Sheffield formation. It consists of hard gray fossiliferous limestone and dolomite and is Upper Devonian in age.

The Juniper Hill shale, N. C. P.—The Juniper Hill shale unconformably overlies the Shell Rock formation and conformably underlies the Hackberry shale. At some places in the north-central province the Juniper Hill shale is undoubtedly directly overlain by the Sheffield formation. The Juniper Hill consists of soft blue fissile shale and also is Upper Devonian in age.

The Hackberry shale, N. C. P.—The Hackberry shale conformably overlies the Juniper Hill and is conformably overlain by the Owen limestone. At a few places it is probably unconformably overlain by the Sheffield formation. This relation is not exposed, however. The Hackberry consists of gray soft exceptionally fossiliferous highly calcareous shales and is Upper Devonian in age.

The Owen limestone, N. C. P.—The Owen conformably overlies the Hackberry formation and unconformably underlies the Sheffield formation. It consists of hard gray to blue fossiliferous limestone ledges interbedded with soft yellow fossiliferous dolomite and some shale. The Owen marks the upper limit of the Lime Creek series and is Upper Devonian in age.

The Sheffield formation, N. C. P. and S. E. P.—The Sheffield formation unconformably overlies the Lime Creek series in the north-central province and unconformably overlies the Cedar Valley limestone in the southeastern province. It is unconformably overlain by the Maple Mill and English River formations in the southeastern province and by the Hampton formation in the north-central province. It is about 125 feet in thickness and consists of blue soft unctuous shale interbedded with brown dolomite. Locally in the upper part some limestone and chert may be seen. Faunally it is very similar to the Chemung of New York, which makes it Upper Devonian in age.

The Sweetland Creek beds, S. E. P.—The Sweetland Creek beds unconformably overlie the Cedar Valley limestone and are unconformably overlain by Pennsylvanian shales in their area of exposure. They consist of greenish blue shales interbedded with blue dolomitic shale. They are very poorly fossiliferous and are probably to be correlated with some part of the Maple Mill formation.

The Maple Mill formation, S. E. P.—The Maple Mill contact with the Cedar Valley is not exposed. It probably overlaps unconformably on to the Cedar Valley limestone. It is conformably overlain by the English River formation. Lithologically it consists of soft blue to gray unctuous pyritic shale. It contains very few fossils but should probably be correlated with the Chattanooga shales.

The English River formation, S. E. P. and N. C. P.—The English River formation conformably overlies the Maple Mill formation and unconformably underlies the Hampton formation. It consists of blue massive siltstone ledges that are filled with casts of fossils. It is correlated with the Hannibal shale of Missouri.

The Hampton formation, S. E. P. and N. C. P.—This formation includes the six following members:

The North Hill member, S. E. P.—The North Hill member lies unconformably over the English River formation. At a few places in the southeastern province it rests possibly on the Maple Mill formation. It is conformably overlain by the Wassonville member of the Hampton formation. Lithologically it consists of semilithographic limestone, quartz siltstone and oölitic limestone. It is correlated with the Chapin member of the Hampton formation in the north-central province and with some portion of the Chouteau of Missouri.

The Wassonville dolomite member, S. E. P.—This member conformably overlies the North Hill member in some parts of the province and unconformably overlies the English River, Maple Mill and Sheffield formations in other parts of the southeastern province. It consists of massive brown dolomite ledges interbedded with white very fossiliferous chert. It is correlated with the Maynes Creek member of the Hampton formation of the north-central province and with some portion of the Chouteau of Missouri.

The Chapin member, N. C. P.—The Chapin member lies unconformably over the Sheffield formation and conformably under the Maynes Creek member of the Hampton formation. It consists of hard gray thin-bedded limestone and oölitic limestone. It is correlated with the North Hill member of the southeastern province and with some portion of the Chouteau of Missouri.

The Maynes Creek member, N. C. P.—The Maynes Creek member conformably overlies the Chapin member and conformably underlies the Eagle City member of the Hampton formation. It consists of massive brown fossiliferous dolomite interbedded with white exceptionally fossiliferous chert. It is correlated with the Wassonville member of the southeastern province and is closely related to the Chouteau of Missouri.

The Eagle City member, N. C. P.—The Eagle City member conformably overlies the Maynes Creek member and conformably underlies the Iowa Falls member of the Hampton formation. It consists of brown and gray limestone in the base, dolomite in the central part, and lithographic and oölitic limestone at the top. Faunally it resembles the Chouteau of Missouri. The Eagle City probably is younger than any portion of the Chouteau, but it has a fauna that was derived directly from that of the Chouteau.

The Iowa Falls member, N. C. P.—The Iowa Falls member conformably overlies the Eagle City member of the Hampton formation and is unconformably overlain by the Alden limestone. It consists entirely of brown dolomite ledges which for the most part are very poorly fossiliferous. It probably is younger than any portion of the Chouteau of Missouri, but it has a fauna that was derived directly from the Chouteau fauna, and it should therefore be considered a part of the Hampton formation of Iowa.

The Burlington formation, S. E. P.—The Burlington limestone unconformably overlies the Hampton formation and conformably underlies the Keokuk limestone. It consists of massive brown crinoidal limestone in the base, brown dolomite interbedded with much chert in the central portion, and gray and green limestones interbedded with chert in the upper portion. It is correlated with the Burlington of Missouri.

The Keokuk formation, S. E. P.—The Keokuk limestone conformably overlies the Burlington limestone and grades conformably into the Warsaw formation. It consists in the basal part of soft yellow dolomite interbedded with much chert and of massive blue shaly fossiliferous limestone beds in the top. It is correlated with the Keokuk beds of Missouri and Indiana.

The Warsaw formation, S. E. P.—The Warsaw formation lies conformably over the Keokuk limestone and is unconformably overlain by the Spergen formation. It consists in the lower portion of soft black and gray fissile shale filled with geodes and in the upper part of blue massive limestone interbedded with shale and dolomite.

The Spergen Formation S. E. P. and N. C. P.—The Spergen of the S. E. P. unconformably overlies the Warsaw formation and unconformably underlies the St. Louis limestone. It consists of brown dolomitic limestone beds and is correlated with the Spergen of Indiana.

It is questionable whether the Spergen is present in the N. C. P. The Alden limestone of Hardin county and the Gilmore City limestone of Humboldt and Pocahontas counties suggest Spergen both lithologically and faunally. The large crinoid fauna in the base of the Gilmore City limestone carries a large number of Kinderhook genera. The Alden limestone, which is correlated with the Gilmore City limestone in this paper, lies unconformably on the upper surface of the Iowa Falls member of the Hampton formation. This relation seems to suggest that they should not be considered to be Kinderhook in age.

The St. Louis limestone, S. E. P. and N. C. P.—The St. Louis limestone unconformably overlies the Spergen formation and may be seen resting unconformably on several other Mississippian formations. It is conformably overlain by the Ste. Genevieve formation. Lithologically it consists of peculiar wavy beds of blue to gray limestones that are usually strongly brecciated. These limestone ledges are interbedded with shale and dolomite.

The Ste. Genevieve formation, S. E. P. and N. C. P.—The Ste. Genevieve unconformably overlies the St. Louis limestone and is unconformably overlain by beds of Pennsylvanian age. It consists of gray, blue, green, black and reddish shales that are very fossiliferous in their upper part. The formation is correlated with the Ste. Genevieve of Missouri.

Acknowledgments

The writer is most indebted to Dr. A. O. Thomas of the University of Iowa, whose careful guidance both in the field and in the laboratory has greatly aided in the production of this paper. Large collections of fossils made by Doctor Thomas throughout the region were turned over to the writer.

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STRATIGRAPHY AND PALEONTOLOGY

Southeastern Iowa Province

INTRODUCTION

The basal formations of the Kinderhook are confined, with the exception of one small group of exposures in Marshall and Tama counties, to the southeastern Iowa province. The Maple Mill shale formation is not exposed northwest of Washington county. The most northwesterly exposures of the English River formation are found along Iowa river in Marshall and Tama counties.

The Hampton formation is much less developed in the southeastern Iowa province than in the north-central province. Only the two basal members of this formation are exposed in southeastern Iowa.

The basal Kinderhook shale beds have been referred by different writers to the Upper Devonian and to the basal Mississippian. The exact age of these shale beds that occupy the interval between definitely recognized Devonian and definitely recognized Mississippian horizons has long been a disputed question. If the Devonian grades conformably into the Mississippian it is obviously an arbitrary matter as to where the line separating the two is placed.

Lithological changes in beds and changes in faunas are usually inaugurated by some diastrophic movement which changes the conditions of sedimentation and the environment in which the faunas live. If such a diastrophic movement is slow and gentle we cannot expect abrupt changes or marked unconformities at places where sedimentation is in progress when the movement is inaugurated.

It is not possible to draw this line on paleontology alone. The Upper Devonian limestones are characterized by a very abundant fauna. In Chemung time this abundant fauna slowly dwindled until only a very few species were left in the uppermost beds of Chemung age. Following the deposition of the Chemung there was a long period during which life in the continental basins was not abundant. This transition period is represented by such formations as the Chattanooga shale, the Sweetland Creek shale, the Maple Mill shale and the Grassy Creek shale. At the time of the deposition of the Saverton shale, the Louisiana limestone and the Hannibal shale conditions are again favorable for life. The faunas represented in these formations are definitely Mississippian but retain many of the old Devonian genera. The presence of the new fauna, however, determines the age of the beds.

It is obvious that lithology cannot be used alone to establish such a contact. In both Iowa and New York the Upper Devonian shales are very much like the shales that are found in the beds in question. In Missouri the first beds that may be definitely referred to the Mississippian are also shales with like characteristics.

The distribution of these shales should help materially in the matter of their classification. The shales of Chemung age usually directly overlie beds of known Devonian age while the shales in question bear very little relation to the Upper Devonian. These shales spread far and wide over the country and rest on older formations of almost every age. They are found in New York, Ohio, Indiana, Michigan, Illinois, Iowa, Missouri, Tennessee, Kentucky, Arkansas and Oklahoma. These shales are more often overlain by Mississippian strata than underlain by Devonian strata. From this distributional relation it seems likely that the greatest change of conditions took place before their deposition and that they should therefore be assigned an early Mississippian age.

Perhaps the best proof for the Mississippian age of the basal Kinderhook shale beds of Iowa and Missouri is found in the great unconformity that lies between them and the Sheffield formation of Chemung age. This unconformity bevels all of the Sheffield formation, all of the Lime Creek series, all of the Cedar Valley limestone, all of the Niagaran dolomite, and a portion of the Ordovician sediments. In northeastern Missouri the basal part of the Kinderhook shale series is found resting on the Galena limestone.

THE SWEETLAND CREEK BEDS

In 1922 Van Tuyl[3] placed the Sweetland Creek beds in the lower portion of the Kinderhook. They will be considered in this report as belonging to the Kinderhook.

Distribution and Thickness.—The exposures of the Sweetland Creek beds are confined to the lower part of the bluffs on the north side of Mississippi river east of the city of Muscatine in Muscatine county.

[3] Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 71, 1922.

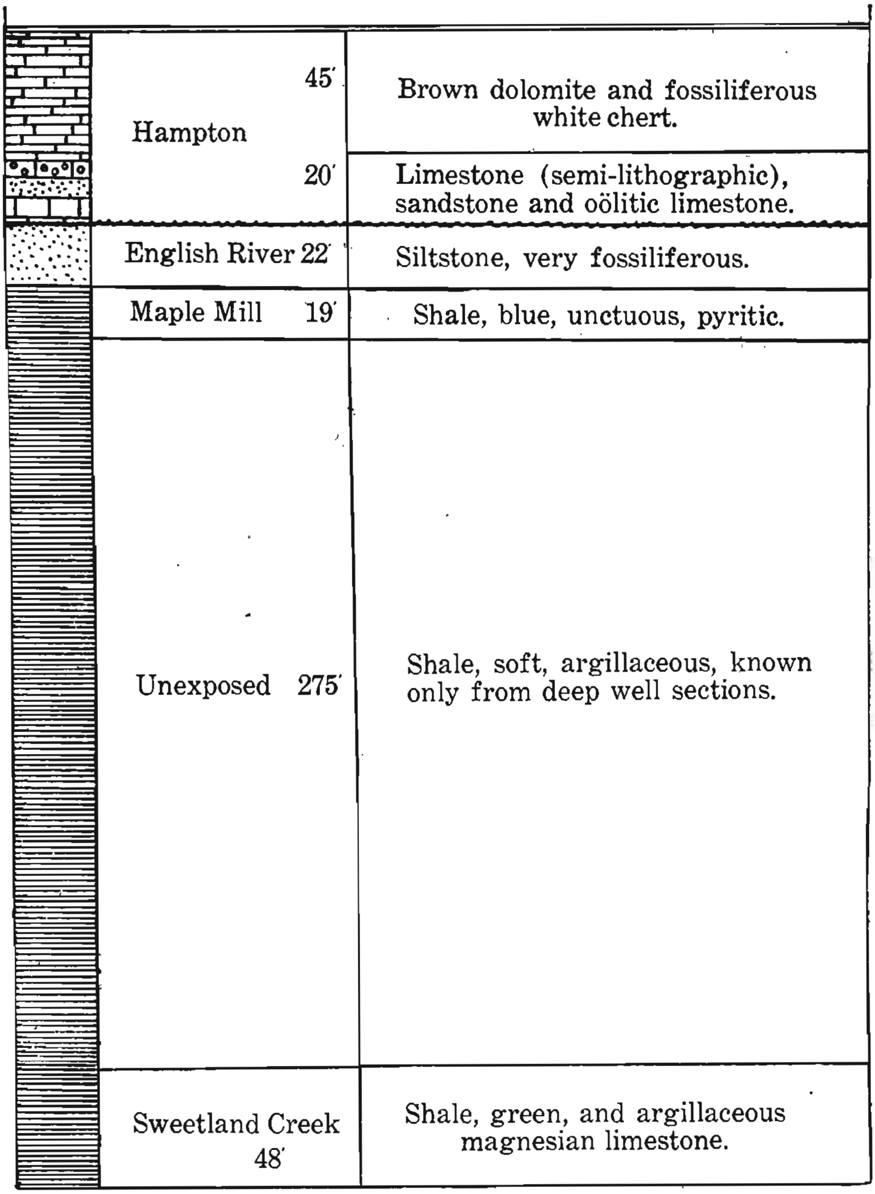

FIG. 46—Composite section of the Kinderhook of Southeastern Iowa.

The exposures are mainly limited to the walls of the creeks that cut the Mississippi bluffs at this locality. The best exposures are located within five miles of the city of Muscatine. Farther to the east the

Sweetland Creek is represented only by discontinuous beds and is often cut out entirely by the "coal measures". The type exposure is located on Sweetland creek about five miles east of the city of Muscatine at 37 of section 27, Sweetland township. It is also well exposed in the valleys of each of the three creeks immediately to the west of Sweetland creek.

A complete section of the Sweetland Creek may not be seen at any one place. At the type section about 20 feet is exposed, which represents only the basal part of the complete section. The uppermost bed of dark shales is almost entirely missing at this place. Van Tuyl places the maximum thickness at 48 feet.

Stratigraphy.—The Sweetland Creek may be seen at several localities in disconformable contact with the underlying Cedar Valley limestone of Upper Devonian age. In the region of its exposure it may also be seen in disconformable contact with the overlying shales of Pennsylvanian age.

South of the area in which the Sweetland Creek is exposed, namely in Des Moines and Lee counties, a blue shale bed underlies the English River gritstone. At the city of Burlington the thickness of this shale bed has been determined through deep well sections to be 375 feet. Only the upper part of this shale bed is exposed in Iowa.

The unconformity at the top of the Cedar Valley limestone becomes more marked toward the south. In Clark county in northeastern Missouri erosion has removed both the Devonian and Silurian beds so that the Kinderhook shale rests unconformably on the Maquoketa shale.[4] If the Kinderhook shale overlaps on to an unconformable surface it is likely that the Sweetland Creek beds do not represent the basal part of the formation.

Paleontology.—The fauna of the Sweetland Creek is very meager and very poorly preserved. The list given by Udden[5] is as follows:

Lingula subspatulata M. and W.
Lingula cf. nuda Hall
Lingula cf. melie Hall
Lingula sp.
Gastropod sp.
Spathiocaris emersoni Clarke
Solenocaris strigata Meek?
Ptyctodus calceolus N. and W.
Rhynchodus cf. excavatus Newb.
Synthetodus sp.

[4] Krey, Frank, Ill. Geol. Survey Bull. 45, p. 50, 1924.
[5] Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey, Vol. IX, p. 302, 1899.

In the lower three inches of the formation just above its unconformable contact with the Cedar Valley limestone may be found a fish tooth conglomerate. The teeth, which are usually very much fragmented, are scattered through this lower hard green dolomitic shale bed. Fish tooth conglomerates of this nature just above unconformable contacts probably originate where the waves break these fish to pieces along the shorelines.

The fish tooth conglomerate is followed by about two and one-half feet of softer green dolomitic shale that is almost unfossiliferous. One layer contains an occasional fish tooth and a few plant remains.

About three feet above the contact of the Cedar Valley limestone is found a hard bluish green dolomite that contains a few indistinct casts of brachiopods. A few specimens of *Lingula* were obtained, also one cast that has been referred to the genus *Reticularia* and one specimen that resembles the brachial valve of a *Schizophoria*. Plant impressions occur at several horizons. This dolomitic horizon is not over two feet in thickness.

Above the dolomite ledge may be seen about eight feet of greenish shales interbedded with darker material. Pyrite and hard green concretions are scattered throughout the mass. The horizon is unfossiliferous except for occasional indistinct plant impressions.

The upper portion of the Sweetland Creek consists of dark bituminous shales filled with pyrite. In the lower part of this zone, which is about 32 feet in thickness, are lenses of blue shale. These lower layers carry the specimens of *Spathiocaris* and *Solenocaris*.

Correlation.—There is very little fauna in the Sweetland Creek to help one in correlation. The presence of *Spathiocaris* and *Solenocaris* would suggest that it be correlated with some part of the Chattanooga shale.

THE MAPLE MILL FORMATION

The Maple Mill shale is exposed only in the southeastern province. Its complete section of 370 feet is known only from deep well sections. The maximum exposed section of the Maple Mill formation is only 60 feet. The Maple Mill is defined as including everything below the English River gritstone and above the Devonian formations.

Distribution and Thickness.—Because of the soft nature of the formation its exposures are practically limited to the base of the Kinderhook-Osage escarpment that forms the common bluff of Mississippi and Iowa rivers. A line of exposures of the Maple Mill may be traced northward from Burlington along the base of the Mississippi bluff. A few miles north of the city the formation dips beneath the level of the flood plain and is not exposed again until the lower valley of Smith creek in Louisa county is reached. Thence it is exposed in several places along the south bluff of Iowa river in Louisa county. These exposures are particularly available for study in the basin of Long creek to the south of Columbus Junction.

FIG. 47.—Maple Mill exposure on Smith creek, Louisa county.

The Maple Mill is not exposed again until the valley of English river in Washington county is reached. Here exposures are found in the bluffs of the river for a considerable distance on either side of the town of Kalona. The best exposures may be seen in the old clay pits one mile south of Kalona.

The Maple Mill is thought to immediately underlie the drift for a considerable distance to the west of Washington county, but it may be studied only through deep well sections which penetrate it. It is thought to underlie the greater part of southeastern Iowa. However, only the upper 60 feet is exposed in the maximum section at Burlington. All other known exposures are of a much smaller nature, few of them exceeding 15 feet.

In well sections the overlying English River formation is not distinguished from the Maple Mill shale. The following thicknesses represent both the English River and the Maple Mill. At Burlington the thickness is 370 feet, at Fort Madison 268 feet, at Keokuk 225 feet, at Winfield 325 feet, at Morning Sun 280 feet, at Fairfield 250 feet, at Sigourney 198 feet, at Ottumwa 165 feet, at Pella 125 feet, at Grinnell 180 feet, and at Marshalltown 145 feet.

It becomes very evident when one studies the distribution of the Sheffield formation in Iowa that much of the shale listed in these well sections very likely belongs to this formation. It is difficult to discriminate between these two shale bodies in well sections, but the Sheffield formation contains a large proportion of dolomitic and calcareous material that is not found in the Kinderhook shales. Much of the material penetrated in well sections in the central part of the state certainly belongs to the Sheffield formation.

Lithologic Character.—Lithologically the Maple Mill is a blue to gray to greenish very soft, unctuous shale. The blue color is by far the most predominating. The shale is usually filled with masses of pyrite and in many localities carries smaller quantities of sphalerite. Locally small calcareous lenses are found but nowhere in such quantities that they might be mistaken for limestone. There are occasional layers of black carbonaceous material. The Maple Mill grades into the overlying English River gritstone, which consists of small white crystalline grains of quartz.

Stratigraphy.—The Maple Mill formation overlies the Devonian limestones unconformably. This unconformable contact is not exposed in the region south of Sweetland creek. The Maple Mill formation probably overlaps on to the unconformable surface, thereby making the Sweetland Creek beds equivalent to some part of the Maple Mill which lies a considerable distance up from its base. The deepest part of the trough in which these shales were deposited probably was somewhere in the vicinity of Burlington, where these shales reach their maximum thickness.

Westward from Mississippi river the Maple Mill formation probably overlaps on to the Sheffield formation. This relation between the two shale beds has never been seen in the field, but from a study of the distribution of these two shale formations such a relation seems inevitable. The English River formation overlaps on to the Sheffield formation and is exposed in this relation at LeGrand.

The Maple Mill grades into the overlying English River gritstone with very little break in lithology at most places. The only evidence of a break between these two formations is found in the English river basin in Washington county, where the lithology changes abruptly from a blue shale filled with carbonaceous material to the fine blue quartz silts of the English River. This contact is exposed in the abandoned clay pit one mile south of Kalona on the south bluff of English river. The English River formation has been considered to be the fossiliferous top siliceous zone of the Maple Mill shale.

Paleontology and correlation.—The fauna of the Maple Mill is very meager and lends very little aid in correlation. Practically the only fossil list known is the one given by Weller. The fossils on which this list is based were collected by Samuel Calvin and J. A. Udden in the clay pit of the Granite Brick Company at Burlington. The ledges from which this fauna was taken are not now exposed.

Fauna of the Maple Mill Shale[6]

Spongiae
- Dictyophyton sp.

Crinoidea
- Crinoid stems

Brachiopoda
- Lingula sp.
- Orbiculoidea sp.
- Schizophoria sp.
- Rhipidomella sp.
- Productus ovatus Hall
- Productus sp.
- Productella sp.
- Eumetria altirostris (White)

Pelecypoda
- Aviculopecten sp.

Gastropoda
- Platyschisma sp.
- Porcellia sp.
- Conularia sp.

Cephalopoda
- Gomphoceras sp.

Crustacea
- Palaeopalaemon newberryi Whitfield

Vertebrata
- Coelacanthus welleri Eastman

Plant remains

A large number of fish remains have been taken from the Maple Mill shale in the vicinity of Burlington. These fish remains were collected by Frank Springer.

Vertebrate Fauna of the Maple Mill Shale[7]

Pristicladodus springeri St. J. and W.
P. armatus St. J. and W.
Cladodus alternatus St. J. and W.

[6] Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 55, 1922.
[7] Moore, R. C., Missouri Bur. of Geol. and Mines, Vol. 21, Second Series, p. 31, 1928.

Cladodus exiguus St. J. and W.
C. exilis St. J. and W.
Mesodmodus exsculptus St. J. and W.
M. explanatus St. J. and W.
Orodus daedalus St J. and W.
O. decussatus St. J. and W.
Pristodus ? acuminatus St. J. and W
Psephodus reticulatus St. J. and W.
Coelancanthus welleri Eastman
Ctenacanthus sculptus St. J. and W.
C. speciosus St. J. and W.
Acondylacanthus gracilis St. J. and W.
Asteroptychius vetustus St. J. and W.
Physonemus depressus St. J. and W.
P. proclivus St. J. and W.

There is very little in these faunas that will help in correlation. Seven of the eighteen species of fishes present in the Maple Mill shale are found again in the sandstone zone of the North Hill member of the Hampton formation. The presence of *Productella* and *Rhipidomella* is slightly suggestive of the Saverton and Louisiana formations of Missouri.

In northeastern Missouri the Louisiana limestone is overlain by the Hannibal shale, which is about 100 feet thick, and is underlain by the Saverton shale, which is approximately 90 feet thick at its type section. The Louisiana limestone thins both to the north and south of its type area. It is missing entirely in the well sections in Iowa. The Louisiana limestone, then, is a lens-shaped mass of limestone in this large shale body.

The Hannibal shale of Missouri carries in its upper ledges a fauna that has been correlated with the English River of Iowa. This English River-Hannibal fauna marks one of the definite horizons of the Kinderhook. It is very easily separated from any other fauna of the Kinderhook and occupies a very limited stratigraphic position.

The English River formation of Iowa directly overlies the Maple Mill shale. From this relation it would seem likely that the upper portion of the Maple Mill might correspond to the poorly fossiliferous lower portion of the Hannibal of Missouri. Lithologically the Maple Mill is more like the Saverton shale than like the Hannibal shale. If the Hannibal shale overlaps on to the Saverton-Maple Mill surface, it may be that the English River is the only portion of the Hannibal represented in Iowa. In this case the Saverton of Missouri would be correlated with some portion of the Maple Mill. In time position the Louisiana limestone would occupy the interval between the deposition of the Maple Mill and the English River. At present this problem cannot be definitely settled.

THE ENGLISH RIVER FORMATION

The exposures of the English River formation are confined to the southeastern Iowa province with the exception of a few exposures along Iowa river near the city of LeGrand in Marshall county.

Distribution and Thickness.—The exposures of the English River formation are limited to the bluffs of Mississippi, Iowa and English rivers and their tributary streams. The English River is very well exposed at the city of Burlington and in the creek valleys immediately north of the city. In the northern part of Des Moines county the English River dips beneath the level of the flood plain of Mississippi river and is not exposed again until Smith creek in Louisa county is reached. Several good exposures are found in the creeks that enter Iowa river from the south in Louisa county and these exposures are particularly well developed in the lower basin of Long creek south of Columbus Junction. Very good exposures are found along the bluffs of English river in Washington county, where the type sections are located. The best exposures are located in the old clay pits one mile south of the town of Kalona in the south bluff of the river. The next place where the English River is exposed is over 100 miles to the northwest of Washington county in the Iowa river valley near LeGrand.

The English River formation differs somewhat in thickness at various localities. This is due mainly to a small unconformity at its top where considerable material has been removed locally. At Burlington its average thickness is about 22 feet, in Louisa county it is rarely over 15 feet, and in Washington county it would average less than eight feet. Abrupt local variations are found in certain localities, however.

Lithologic character.—The English River formation consists of massive blue siltstone ledges in which the individual grains are of clear white quartz. Mechanical analysis shows that 70 per cent of the material falls in the 1/16 to 1/32 mm. size grade. Practically none of the material is larger than this. The majority of the crystals show good crystal boundaries and as a whole the material shows little evidence of transportation. The color of the material is usually blue or gray, much like the underlying Maple Mill shale. Occasionally the upper beds are of a brownish yellow color. This color is developed just below the contact of the English River with the overlying formations.

Stratigraphy.—The English River lies with apparent conformity on the Maple Mill formation and is differentiated from the Maple Mill only by its massive sandy nature and its abundant fossil remains. It has been considered to be the upper fossiliferous part of the Maple Mill formation.

In the greater part of its area in Iowa the English River lies unconformably beneath the Hampton formation. In Missouri apparently no such relation exists between the Hannibal and Chouteau formations.

At Burlington the English River appears to underlie the Hampton conformably. Several of the species of fossils found in the English River continue right across the line. The only suggestion of a break between the two formations at Burlington is found in the leached yellow ledge at the top of the English River formation. This material is thought to have been leached after the retreat of the English River sea and before the advance of the Hampton sea.

To the north and west of Burlington this unconformity becomes more and more marked. It is very clearly marked in Washington county in the type sections of the English River. In the exposures in Iowa river valley near LeGrand the English River is represented by a conglomerate of large blocks in which nearly every zone of the English River is found.

This stratigraphic break will be taken up in detail in a separate chapter at the end of the description of the Hampton formation of the southeastern Iowa province.

Paleontology.—The English River fauna is one of the most distinctive and most easily recognized faunas in the Iowa Kinderhook. It contains a very characteristic assemblage of fossil species that do not occur together in any other part of the series. The fauna is exceptionally prolific both in individuals and in species. The fossils are always preserved as casts in this sandy material.

The fauna of the English River at Burlington has been fully listed by both Weller[8] and Van Tuyl[9] and will not be repeated here.

Faunal list from the English River at the railroad cut exposure in the northeast corner of section 19, R. 3 W., Twp. 73 N., in Louisa county.

Brachiopoda
- Schellwienella inaequalis (Hall)
- Chonetes illinoisensis Worthen
- Productus mesicostalis Weller
- Productus curtirostris Winchell
- Productella concentrica Hall
- Orbiculoidea capax White
- Schizophoria swallovi (Hall)
- Schizophoria sp.
- Productella numularis (Winchell)
- Paryphorhynchus transversum Weller
- Composita corpulenta (Winchell)
- Spirifer subrotundus Hall
- Syringothyris extenuatus Hall
- Eumetria altirostris White

Pelecypoda
- Posidonomya ambigua Winchell
- Grammysia amygdalinus Winchell
- Grammysia plena Hall
- Edmondia aequimarginalis Winchell
- Edmondia burlingtonensis W. and W.
- Edmondia quadrata W. and W.
- Mytilarca occidentalis W. and W.
- Schizodus iowensis Weller
- Goniophora jennae Winchell
- Pterinites whitei Winchell

Gastropoda
- Bellerophon panneus White
- Bellerophon bilabiatus W. and W.
- Murchisonia quadricincta Winchell
- Strophostylus bivolve W. and W.
- Platyschisma barrisi (Winchell)
- Platyschisma depressa Weller
- Naticopsis depressa Winchell

Pteropoda
- Dentalium grandaevum Winchell

Cephalopoda
- Orthoceras indianense Hall
- Orthoceras whitei Winchell

The following faunal list was made from collections taken from the abandoned clay pits one mile south of Kalona.

Brachiopoda
- Orbiculoidea capax (White)
- Schellwienella inaequalis (Hall)
- Productus mesicostalis Weller
- Productus curtirostris Winchell
- Productella numularis (Winchell)
- Chonetes illinoisensis Worthen
- Chonopectus fischeri N. and P.
- Schizophoria swallovi (Hall)

[8] Weller, Stuart, St. Louis Acad. of Sci., Vol. 10, p. 57, 1900.
[9] Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 59, 1922.

Paryphorhynchus striatocostatum M. and W.
Spirifer biplicatus Weller
Spirifer subrotundus Weller
Spirifer maplensis Weller
Eumetria altirostris White
Athyris corpulenta (Winchell)

Pelecypoda
Pteronites whitei (Winchell)
Mytilarca occidentalis (W. and W.)
Grammysia amygdalinus (Winchell)
Schizodus iowensis Weller
Glossites elliptica (Winchell)
Edmondia jejunus (Winchell)
Edmondia quadrata (W. and W.)
Edmondia burlingtonensis (W. and W.)
Mytilarca fibristriata (W. and W.)
Leiopteria spinulata (Winchell)
Aviculopecten caroli Winchell
Porcellia obliquinoda White

Gastropoda
Bellerophon blairi M. and G.
Bellerophon panneus White
Bellerophon bilabiatus W. and W.
Strophostylus bivolve (W. and W.)
Straparollus ammon (W. and W.)
Straparollus angularis Weller
Platyschisma barrisi (Winchell)
Platyschisma depressa Weller
Agonites opimus (W. and W.)
Platyschisma missouriensis Weller

Pteropoda
Dentalium grandaevum Winchell

Cephalopoda
Orthoceras whitei Winchell
Orthoceras indianense Hall

The English River formation differs considerably in thickness throughout the region, owing mainly to the unconformity at its top. It is possible to distinguish in the formation different fossiliferous zones which must be defined by the fauna alone because of the similarity of the lithology throughout. The maximum thickness of the formation in Iowa is about 32 feet. The lower 22 feet of this section may be seen at Burlington and the upper part may be seen at only a few places along English river in Washington county. The best exposure of this upper part may be seen on the south bank of English river at 82 of section 8, Range 8 West, Township 77 North.

One part of the English River contains a faunal assemblage that is definite enough to be used as a datum plane. This will be designated as the *Chonopectus fischeri* zone. This zone is about six feet thick and is characterized mainly by a great number of individuals of the species named. At Burlington the zone is found at the top of the English

River section and may be found at this same stratigraphic position at a number of places in the region. However, in the English river basin a considerably different relation is often found. At several exposures the zone is missing entirely and at several other exposures it is found to be a considerable distance down in the section. This relation is due to the unconformity that bevels its surface in this locality.

The *Chonopectus fischeri* zone should be established by paleontological methods rather than by stratigraphy. Individuals of this species crowd the beds of this zone, and associated with this form are found great numbers of *Chonetes logani*. *Paryphorhynchus striatocostatum* occurs only rarely outside of this zone while *Spirifer biplicatus, Syringothyris extenuatus* and *Schellwienella inaequalis* occur much more abundantly in this zone than in any other part of the formation.

English River at LeGrand.—The English River beds are exposed beneath the Hampton formation along Iowa river in the west part of Tama county and in the east part of Marshall county. These exposures are found at intervals along either side of the river for a distance of about two miles from the old mill one mile north of LeGrand in Marshall county, to the town of Butlerville, in Tama county.

At only one place in the area are English River strata actually exposed but their contact with the overlying limestone is marked by a line of bog springs. By digging in the bluffs near these springs a contact may often be exposed. In the exposure at the old mill a mile north of LeGrand about eight feet of greenish shaly material may be seen underlying the oölitic limestone. The contact between the two formations appears to be unconformable. None of this material is fossiliferous, so it is not possible to state whether it should be classed with the Sheffield formation or with the English River.

At an old quarry at 77 of section 9, Indian Village township, in Tama county, an exposure that proved to be very fossiliferous was made by digging. The exposure consists of a conglomerate of large blocks of English River material. These blocks were all tumbled together and cemented with travertine in a striking manner. Fossils from many different horizons in the formation were found in these blocks. A few of the blocks were almost unfossiliferous while others were exceptionally fossiliferous. The entire thickness of the formation at this place was not over three feet, and its contact with a soft bluish green shale was easily exposed by more digging. The break between the English River conglomerate and the overlying oölitic limestone was very sharp and appeared to be unconformable.

This conglomerate probably represents blocks of English River material that rolled from some nearby elevation into small valleys excavated in the Maple Mill or Sheffield formations during the period of erosion following the deposition of the English River. This exposure is over 100 miles northwest of the nearest known English River exposures.

English River fauna collected from the exposure at 77 of Section 9, Indian Village township, Tama county.

Brachiopoda
- Productus mesicostalis Weller
- Spirifer subrotundus Hall
- Athyris corpulenta (Winchell)

Pelecypoda
- Posidonomya ambigua Winchell

Gastropoda
- Bellerophon panneus White
- Bellerophon vinvulata W. and W.
- Bellerophon bilabiatus W. and W.
- Bellerophon sp.
- Strophostylus bivolve W. and W.
- Bellerophon blairi M. and G.
- Straparollus macromphalus Winchell
- Straparollus angularis Weller
- Platyschisma depressa Weller
- Platyschisma missouriensis Weller
- Platyschisma barrisi (Winchell)
- Bucanopsis deflectus Weller
- Phanerotimus paradoxus Winchell
- Euphemus sp.

Pteropoda
- Dentalium grandaevum Winchell

Cephalopoda
- Agonites opimus (W. and W.)
- Orthoceras whitei Winchell
- Cyrtoceras unicorne Winchell

The brachiopod and pelecypod elements are noticeably absent in this western development of the English River formation. The most abundant species in this fauna is the large *Platyschisma missouriensis.*

Correlation.—The English River has been correlated with the Hannibal formation of Missouri by Weller, Van Tuyl, and Moore. Of the 28 species of brachiopods found in the Hannibal of Missouri 12 are found in the English River. Of the 15 species of pelecypods found in the Hannibal nine are found in the English River. The gastropod element in the Hannibal is very small, with only four representatives, and of these only one is found in the English River. Two cephalopods are found in the Hannibal and one of these occurs in the English River. The English River fauna contains 48 per cent of the Hannibal species.

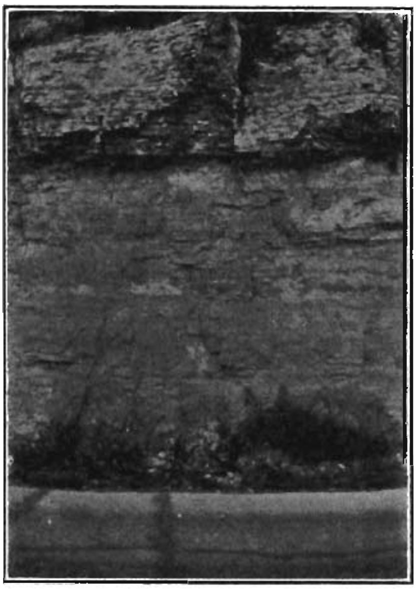

FIG. 48.—English River exposed at North Hill, Burlington, Iowa.

THE HAMPTON FORMATION

The lower members of the Hampton formation are exposed in the southeastern province in Iowa. In this province the Hampton has been divided into two members, the North Hill at the base and the Wassonville overlying. The North Hill member is named from the road cut around North Hill in the city of Burlington, where a complete section of the member may be seen. The Wassonville member corresponds to the Wassonville limestone as delimited by Bain[10] in 1896.

The North Hill Member

The North Hill member contains all Kinderhook beds above the English River formation and below the brown dolomites of the Wassonville member. It corresponds to beds 3, 4, 5 and 6 of Weller.[11]

Distribution and Thickness.—The North Hill member has a limited distribution in the southeastern province and is exposed best in the immediate vicinity of Burlington. Exposures may be traced northward

10 Bain, H. F., Geol. of Washington County, Iowa Geol. Survey, Vol. V, p. 134, 1895.
11 Weller, Stuart, St. Louis Acad. of Sci., Vol. 10, p. 61, 1900.

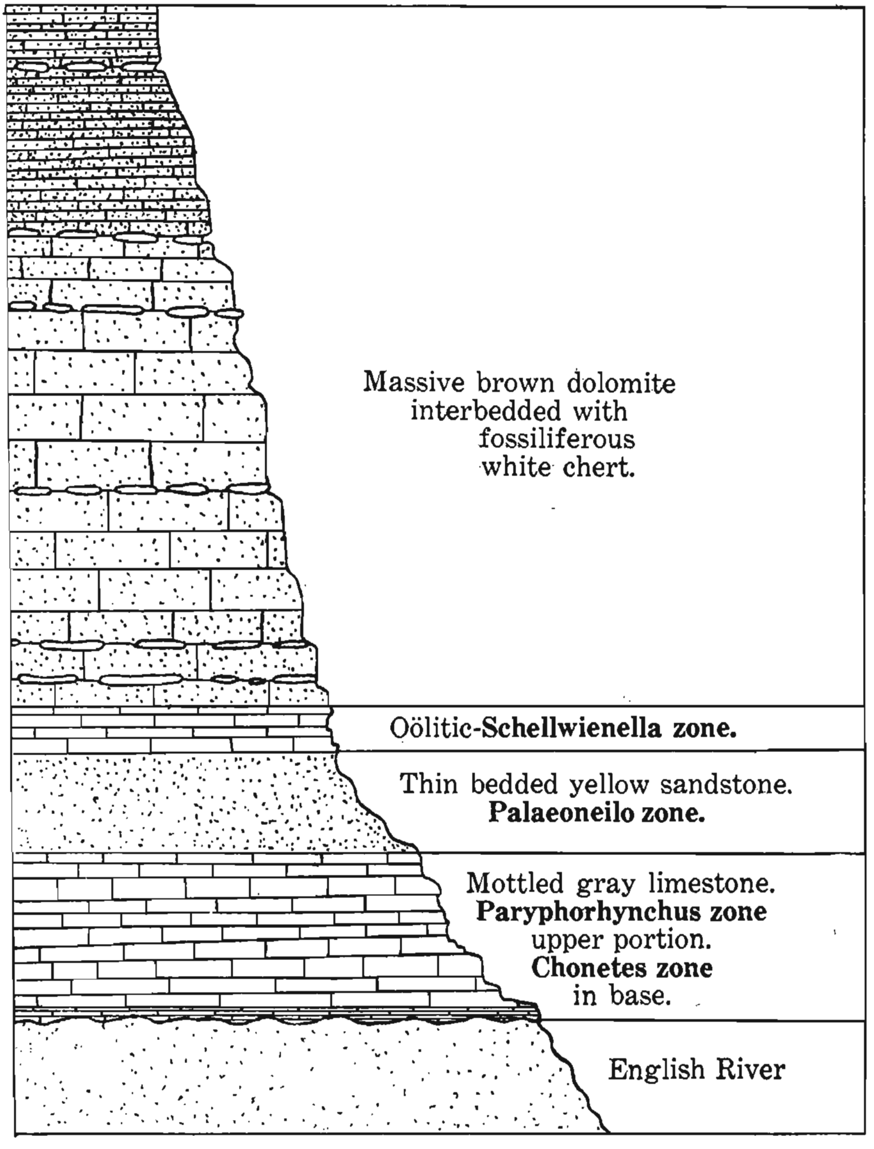

FIG. 49.—Wassonville and North Hill members of the Hampton formation in southeastern Iowa. The uppermost group of beds is referred to the Wassonville and the three underlying are referred to the North Hill. Scale: 1 inch equals 16 feet.

along the Mississippi bluff throughout the entire length of Des Moines county. In the lower valleys of the creeks that are tributary to Mississippi river limited exposures of the member may be seen.

In Louisa county the exposures are not so abundant, but they may be identified in the valleys of the creeks and along Iowa river bluff as far west as Honey creek near Morning Sun. These exposures in Louisa county represent only the upper beds of the member. The best exposure of the member in this county may be seen in the county quarry at 113 of section 23, Range 3 West, Township 73 North. The entire section of the North Hill member may be seen here, and its relations to the underlying English River and the overlying Wassonville are clearly shown. At this point the member is only eight feet thick.

The North Hill member is approximately 20 feet in thickness at the city of Burlington, but as it is traced to the north and west the lower layers pinch out against the underlying English River formation. In the lower valley of Smith creek in Louisa county it is only 15 feet in thickness and slightly farther west on Honey creek it is only eight feet thick. In the lower valley of Long creek south of Columbus Junction it cannot be distinguished from the overlying Wassonville dolomite.

Lithologic Character.—Lithologically the North Hill member is not a unit at all. It consists of an oölitic limestone at the base, followed by a semilithographic limestone, followed by a sandstone, and capped with an oölitic limestone.

The units of the North Hill member have been given zone names for the most prominent fossils which they contain. These zones correspond to the beds described by Weller[12] in 1900. The following table gives the zone names and their equivalents.

4. *The Schellwienella zone* is named for *Schellwienella planumbona* Weller, which characterizes the zone. This zone is equivalent to the oölitic bed 6 of Weller.
3. *The Palaeoneilo zone* is named for *Palaeoneilo barrisi* (W. and W.), which occurs abundantly in the horizon. This zone is equivalent to the yellow sandstone bed 5 of Weller.
2. *The Paryphorhynchus zone* is named for *Paryphorhynchus striatocostatum* M. and W., which occurs most abundantly in the zone. It is equivalent to the mottled limestone bed 4 of Weller.
1. *The Chonetes zone* is named for *Chonetes gregarius* Weller, which crowds certain parts of the horizon. This zone is equivalent to bed 3 of Weller.

The *Chonetes* zone consists of dark, bluish black thin-bedded lime-

[12] Weller, Stuart, St. Louis Acad. of Sci., Vol. 10, p. 61, 1900.

stone that is in places oölitic in its upper part. The zone is nowhere over nine inches in thickness and is usually filled with more or less fragmented fossils.

The *Paryphorhynchus* zone is a semilithographic limestone whose lithology is quite similar to that of the upper ledges of the Chouteau at Newark, Missouri. The peculiar coloration of this zone makes it easily distinguishable throughout the region. It appears everywhere as an uneven mottled thin-bedded drab and brown limestone. Each of its individual beds is made up of irregular zones of yellowish drab limestone and darker zones of brown limestone. These color variations are closely spaced within the beds, giving the limestone an irregular mottled appearance on a vertical face. The material is hard, breaks with a conchoidal fracture and is very resistant to weathering.

This limestone is almost identical in lithologic character with the Louisiana limestone. For this reason it has been thought to be a northern extension of this limestone body. The fauna, however, shows definitely that this is not true.

The *Palaeoneilo* zone consists of about six feet of soft yellow rather thin-bedded sandstone. Under the microscope the material may be seen to consist of irregular particles of pure quartz mainly of the silt size. The cementing material is calcite and limonite. Lithologically the material resembles very much the English River.

The *Schellwienella* zone consists of about three feet of hard gray rather thin-bedded fossiliferous oölitic limestone. The zone is rather constant in thickness over the whole area of exposure.

Stratigraphy.—The North Hill member lies disconformably on the English River formation. The unconformity is not well shown in this immediate region of the southeastern province because of a lack of exposures in which the contact between the North Hill member and the English River formation may be seen.

The North Hill member can be demonstrated to overlap on to the English River surface. Each of the zones from the base upward may be traced a little farther to the northwest. Only the upper zones of the member are present in Louisa county. In Washington county the Wassonville member lies directly on the English River.

The North Hill member underlies the Wassonville member conformably. The lithologic break between the oölitic limestone of the North Hill member and the dolomite of the Wassonville member is sharp, but the fauna continues into the overlying beds with little or no break.

Paleontology and Correlation.—The fauna of the North Hill member has been listed by Weller[13] in 1901, by Van Tuyl[14] in 1922 and by Moore[15] in 1928.

This fauna is quite closely related to that of the underlying English River formation. There are 88 species listed from the underlying English River and Maple Mill formations in Iowa and 22 of these are found in the North Hill member. When the entire faunal assemblage is considered these species must be regarded as holdovers in the new formation from the English River. The Chouteau element is by far the most prominent in the fauna.

The North Hill fauna contains a large number of species that occur in the fauna of the Chouteau at Newark, Missouri. Moore has listed 71 species from the Newark beds and of these 24 are found in the North Hill member. There are 38 brachiopods present in the Newark fauna and of these 17 occur in the North Hill fauna.

The North Hill member contains most of the common index fossils of the members of the Hampton formation that overlie it. The fauna of the *Chonetes* zone is small and helps very little in correlation. The fact that it is a limestone would tend to place it in the Hampton formation rather than in the English River because the English River has no limestone whatsoever. The occurrence of *Rhipidomella burlingtonensis* also suggests the Hampton formation.

The fauna of the *Paryphorhynchus* zone also is limited. *Paryphorhynchus striatocostatum* and *Rhynchopora pustulosa* occur abundantly in the zone and both are characteristic fossils of the Hampton formation. The lithology of this bed is very similar to that of the upper part of the Chouteau section at Newark, Missouri.

The *Palaeoneilo* zone contains a very abundant fauna in which are found for the first time many of the index species that range throughout the entire Hampton formation. The presence of *Spirifer platynotus, Camarophorella lenticularis, Productus arcuatus, Leptaena analoga, Reticularia cooperensis,* and *Bucanopsis perelegans* is very characteristic of the Hampton formation and an important number of these species are found in the Chouteau of Missouri. On the basis of

[13] Weller, Stuart, St. Louis Acad. of Sci., Vol. 11, p. 147, 1901.
[14] Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 58, 1922.
[15] Moore, R. C., Missouri Bur. of Geol. and Mines, Vol. 21, 2d Ser., p. 25, 1928.

these Chouteau species these lower three zones are correlated with some portion of the Chouteau of Missouri rather than with the Hannibal.

The *Schellwienella* zone has been correlated by Moore[16] with the Chouteau. The fauna contains many species that are characteristic of both the Chouteau of Missouri and the Hampton of Iowa. *Schellwienella inflata, Leptaena analoga, Chonetes logani, Productus arcuatus* and *Productella concentrica* are characteristic of the *Missouri* Chouteau. *Spirifer platynotus, Schellwienella planumbona, Productus arcuatus, Athyris crassicardinalis* and *Straparollus obtusus* are characteristic of the Hampton of Iowa.

The North Hill member is seen again in the north-central province at LeGrand, in Marshall county. Here the cherty Wassonville member is underlain by 18 feet of gray oölitic limestone that contains a fauna very similar to the fauna of the *Schellwienella* zone of the North Hill member. Farther north in Franklin county the North Hill member is represented by the Chapin, which consists of about 30 feet of hard gray limestone overlain by oölitic limestone. The Chapin section probably has beds in its base which are older than the North Hill member.

It is difficult to state just which part of the Chouteau of Missouri the North Hill member represents. Lithologically the base of the North Hill resembles the upper part of the Chouteau at Newark, Missouri. It is the opinion of the writer that the North Hill member is equivalent to the upper part of the Chouteau of Missouri.

The Wassonville Member

Distribution and Thickness.—The Wassonville member is exposed quite extensively in the southern province. In the northern province its equivalent horizon, the Maynes Creek, also is very well exposed.

In the southeastern province the Wassonville member may be seen capping the oölitic limestone of the North Hill member and underlying the Lower Burlington limestone in all of the exposures in the vicinity of Burlington. It is exposed at a number of places along the bluffs of Mississippi river in Des Moines county. In Louisa county it is very well developed along the southern bluff of Iowa river and in the adjacent creek valleys. The best exposures are along the bluffs of English river in Washington county, where the type sections are located. The type section from whence the name is derived is located at the old Wassonville mill on the south bluff of English river two miles

16 Moore, R. C., Missouri Bur. of Geol. and Mines, Vol. 21, 2d Ser., p. 22, 1928.

north of Daytonville. To the west of Washington county the Wassonville is very poorly exposed in the southeastern province. The Wassonville cherts may be seen occasionally in the creek beds but for the main part the exposures are missing. The northernmost exposure of the Wassonville in the southeastern province is at the town of Amana, in Iowa county. Here about 15 feet of yellow dolomite filled with fossiliferous chert may be seen in the exposure on Price creek in the northern part of the town.

The maximum thickness of the Wassonville member is about 45 feet. It very likely once had a much greater thickness, as concentrates of chert are usually found capping its sections. Its equivalent member, the Maynes Creek, in the northern province attains a much greater thickness. The thickness of the member differs considerably in the area owing to the presence of unconformities both above and below. The minimum thickness of the member may be seen in the vicinity of Burlington, where it is in very few places over five feet thick.

Lithologic character.—The main portion of the Wassonville is a brown massive dolomite in which the beds would average over a foot in thickness, with the exception of the upper ledges. The solubility of the material runs up as high as 94 per cent. Microscopically the material consists of many dolomite rhombohedrons cemented together with calcite and limonite. The maximum sizes belong in the 1/16 to 1/32 mm. size grade, which places the material among the silts.

The Wassonville is particularly characterized by its chert bands, which may be white, black or banded. At least 95 per cent of the chert would be considered as white, however. Between most of the bedding planes may be seen long lenticular masses of chert that at some places appear to be continuous and at others are represented by a discontinuous row of nodules. These chert masses are in most cases crammed with fossils. In a few of the exposures the chert has weathered to a crumbly mass of white powder and in these exposures it is very easy to obtain the fauna. The chert bands range in thickness from about eight inches to less than two.

Stratigraphy of the Wassonville member.—The Wassonville member conformably overlies the North Hill member in the southeastern part of the province. However, in the English river basin in Washington county the Wassonville overlies the English River directly and is disconformable. Evidence will be given to show that the Wassonville overlies the Maple Mill directly at some places although the actual contacts are not exposed. The Wassonville also overlies the Sheffield directly in one exposure in the southeastern province.

The Wassonville member contains a series of white chert bands that can be definitely distinguished from each other by their distinctive faunas. In the English river basin are four of these chert bands that occupy rather definite stratigraphic horizons. The uppermost of these four bands carries a fauna that may be very easily recognized and will therefore be used as a datum plane over a short distance in the English river basin.

The upper chert band that is to be used as a datum plane may be distinguished from the other three very easily. It is composed mainly of fragmented stems and plates of crinoids. Plates of several species of *Platycrinus,* a *Rhodocrinus* and a *Cactocrinus* may be distinguished. Intermingled with the crinoidal fragments may be seen other species that are characteristic of this chert band alone. A small form of *Leptaena analoga* occurs very abundantly and appears to be confined to this horizon. Two species of *Rhombopora,* two of *Cystodictya* and one of *Fenestella* are very common in the horizon. The presence of the crinoidal material, the numerous bryozoa, and the small form of *Leptaena* are definite indications of this horizon within the English river valley.

The English River—Hampton unconformity.—The English River formation of Iowa has been thought by many to underlie the limestones of Hampton age conformably. No previous writer has placed a disconformity between the English River and the upper limestone of Kinderhook age. No break of any kind is recognized between the Hannibal and Chouteau formations of Missouri. The Hampton of Iowa is equivalent to part of the Chouteau of Missouri and the English River has been correlated with the Hannibal.

It is one of the purposes of this paper to demonstrate the unconformity between the English River formation and the overlying Hampton formation. It should be kept in mind that the author is dealing only with the strata that are exposed in Iowa and that this unconformity need not be projected into Missouri. It is evident that the faunas of the English River and Hampton formations are very closely related and that at some place there was continuous sedimentation between the two formations. It is possible that although there is a marked break between the formations in Iowa there might have been continuous deposition in Missouri. Furthermore the unconformity that exists at the base of the Hampton formation is much more sharply marked in the northern part of the state than in the southern.

The Hampton formation overlaps on to beds of older age. In the southeastern province it overlaps on to the English River surface and the Maple Mill surface, and finally at a few localities it may be seen resting directly on shales of Sheffield age. In the north-central province the Hampton rests on the English River at one locality in the very southern part of the province. At all other places in the north-central province it rests unconformably on different members of the Sheffield formation.

The faunal break between the two formations is not at all sharp at Burlington. Several species found in the English River at Burlington continue on into the North Hill member. At all other localities in Iowa the faunal break is very sharp. The sharp faunal break was one of the direct causes for the work that has been done on this contact.

It is obvious that it would not be possible to determine such an unconformity by direct observation on the sections. The largest and best exposures are seldom over a score of feet in length. The presence of the thick overlying drift in Iowa forces the stratigrapher to use fossil zones in determining his horizons and therefore definite life zones have been established in both the English River and Hampton formations. It is largely through the tracing of these life zones areally that this unconformity has been established.

The zones of the North Hill member pinch out against the English River surface to the northwest of Burlington. The member is known to definitely overlap on to the English River, for each of the zones in order from the base upward may be traced a little farther to the northwest. The *Chonetes* zone may be distinguished only in the immediate vicinity of Burlington. The *Paryphorhynchus* zone is exposed in the valleys of the creeks that enter Mississippi river in the northern part of Des Moines county. It is represented by a thin dolomitic bed in a few of the easternmost creek valleys that enter Iowa river in Louisa county. Both *Palaeoneilo* and *Schellwienella* zones may be seen on Smith creek below the wagon bridge at 46 of section 31, Range 3 West, Township 73 North. The *Schellwienella* zone is exposed in the lower valley of Honey creek to the north and east of Morning Sun. In the valley of Long creek south of Columbus Junction the whole North Hill member is represented by five feet of brownish dolomite. In the English river valley in Washington county none of the North Hill member is present.

The unconformity between the two formations is very well shown in the English river valley. At all known exposures in this area the Wassonville rests on the English River. Descriptions will be given of the relations between the two formations at four different localities along English river from Kalona to the old Wassonville mill, which is six miles up English river from Kalona.

The Kalona clay pit section is located on the south bluff of English river at 11 of section 19, Range 7 West, Township 77 North. About six feet of English River gritstone may here be seen overlying the Maple Mill shales and underlying about ten feet of Wassonville dolomite. The English River material is all below the *Chonopectus fischeri* zone and represents only the lower blue-gray ledges, which are filled with molluscs. The basal portion of the Wassonville consists of about six feet of soft blue-gray shale filled with irregular chunks of English River gritstone. In this clay pit the shale bed ranges from six feet to less than two feet in thickness and carries the characteristic Wassonville fish fauna in its base. Only occasional fish teeth may be found at this locality, but at certain other localities in the immediate vicinity fish tooth conglomerates may be found at this horizon. This shale consists of material from the Maple Mill and English River surfaces that has been reworked by the encroaching Hampton sea and concentrated in the base of the Hampton. The basal portion of the dolomite which overlies this shale has present in it a considerable amount of reworked English River grit.

The contact of the Wassonville member with the English River is eight feet below the crinoidal chert band of the Wassonville. The typical Wassonville dolomite ends two and one-half feet below the crinoidal chert band.

The *second section* is located on the south bank of English river about one hundred feet downstream from the wagon bridge at 81 of section 8, Range 8 West, Township 77 North. At this point about 20 feet of English River material may be seen overlying the Maple Mill shale and underlying the Wassonville. The English River section includes the entire *Chonopectus fischeri* zone and eight feet of material that lies above this zone. The upper surface of the English River, on which the Wassonville rests, is filled with solution pits and the whole upper part is of a peculiar reddish color that probably was caused by weathering before the deposition of the Wassonville. The contact of the English River with the Wassonville at this point is three feet below the upper crinoidal chert band of the Wassonville.[17]

The basal six inches of the Wassonville in this second section consists of reworked English River material mixed with dolomite. Lithologically it is almost identical with the true English River material. It contains a remarkable fish fauna and also an invertebrate fauna that is typically Wassonville in age. These fish remains are often concentrated immediately on the contact between the two formations, but occasionally they occur slightly above the contact. The English River surface is full of solution pits and in these pits are concentrated scores of fish teeth, plates and spines.

Next above the fish tooth bed may be seen about ten inches of reworked Maple Mill shale filled with fragments of English River material. The presence of Maple Mill shale in the Wassonville section shows that at some nearby place erosion had cut entirely through the English River into the Maple Mill and that the encroaching Wassonville sea was rehandling the material and depositing it in its basal ledges.

The true Wassonville dolomite begins just above this shale bed. The lower part of the dolomite contains large amounts of reworked English River material but attains its true dolomitic character a short distance above its contact with the shale. The base of the dolomite contains a few scattered fish teeth and an invertebrate fauna of 37 species.

The *third section* is located one mile up English river from the second section in an abandoned quarry on the north bluff of the river at 69 of section 6, Range 8 West, Township 77 North. The contact of the English River with the Wassonville is not exposed in this quarry but may be seen a few rods downstream. It is assumed that the quarry floor is very near the contact. In this quarry there are 26 feet of Wassonville dolomite below the crinoidal chert band. All four of the chert bands are present.

A short distance downstream on the same side of the river the

[17] A small quarry at 399 of Section 16, Range 8 West, Township 77 North, approximately half way between the Kalona clay pit and the second section, shows three chert bands and twelve feet of Wassonville dolomite underlying the crinoidal chert band.

contact of the English River with the Wassonville is exposed. The Wassonville at this point rests directly on the *Chonopectus fischeri* zone and only about 12 feet of dolomite is present below the crinoidal chert zone.

The fish tooth bed is present again in the base of the Wassonville. These fish teeth are present in the base of the Wassonville in nearly all of the exposures, but at none of them are the teeth located at exactly the same stratigraphic horizon. Evidently the fish were washed ashore after death and rolled back and forth in the waves until they were broken to fragments. This action would concentrate their remains directly on the contact between the two formations and would explain also their varying stratigraphic position. Fish teeth occur all through the Hampton formation, but at no place except at the base of the formation are they gathered into typical fish tooth conglomerates.

The *Wassonville Mill section* is located on the south bank of English river one mile north of Daytonville. This section shows practically the same relation to the English River as the last described section. Twenty-five feet of Wassonville dolomite may be seen below the crinoidal chert horizon. The Wassonville quarry is still in operation and this fact makes possible the collection of large numbers of fossils from the soft chert nodules that are thrown aside during the quarrying operation.

The Wassonville section shows fairly well the relation of the upper part of the section to the Maynes Creek member of the same age in the northern province. Above the typical section may be seen about 20 feet of fragmented chert and weathered dolomite which were concentrated at the top of the section by weathering of the dolomite. The Wassonville of the southeastern province was probably as thick as the Maynes Creek of the northern province.

The Wassonville at Amana.—The Wassonville dolomite is exposed in the northern part of the town of Amana, in Iowa county. The exposure is located within the city limits in the south bank of Price creek about 50 feet downstream from the bridge. At this point about 15 feet of Wassonville dolomite carrying its typical chert bands may be seen overlying the blue dolomitic shales of the Sheffield formation. The blue dolomitic shales carry a typical Sheffield fauna. The Wassonville dolomite has overlapped the English River and the Maple Mill and in this section rests unconformably on the Sheffield. Shales in thicknesses as

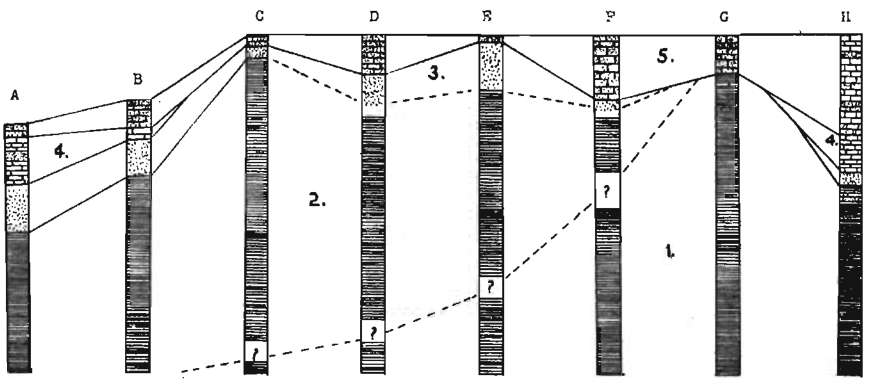

FIG. 50.—Kinderhook Correlation Chart for Southeastern Iowa (Crinoidal chert band in top of Wassonville is used for a datum plane). Vertical scale: 1 inch equals 100 feet.

5. Wassonville member.
4. North Hill member.
3. English River formation.
2. Maple Mill formation.
1. Sheffield formation.
A. Burlington.
B. Long creek, southeast of Columbus Junction.
C. Kalona clay pit, one mile south of Kalona.
D. Abandoned quarry, at 29 of Section 16, Range 8 West, Township 77 North.
E. Section 2 at 81 of Section 8, Range 8 West, Township 77 North.
F. Wassonville Mill section.
G. Section at Amana.
H. Section at LeGrand.

much as 175 feet that have been referred to the Maple Mill are found in well sections to the south and west of here. The English River is actually exposed over 100 miles northwest of Amana. It would seem that a large amount of erosion must have taken place before the Wassonville could have been deposited directly on the Sheffield in this region.

The English River of Marshall and Tama counties.—The English River is exposed along Iowa river in the eastern part of Marshall county and in the western part of Tama county. It consists here of a conglomerate of large blocks cemented with travertine. The conglomerate represents blocks of English River material that had tumbled down into a small valley that had been eroded in the Maple Mill or Sheffield formations before the deposition of the Hampton.

In this section may be seen 18 feet of oölitic limestone that is equivalent to the upper part of the North Hill member at Burlington. This oölitic limestone overlies the English River and is overlain by the typical brown dolomites filled with chert bands.

Summary of the evidence for the English River-Hampton unconformity.

1. The Hampton formation overlaps and rests on three different formations.
2. Abrupt changes in the thickness of both the upper part of the English River and the base of the Hampton are seen.
3. The North Hill member occupies a low in the English River surface.
4. The oölitic limestone at LeGrand also occupies a valley that was eroded before the deposition of the oölite.
5. The fish tooth conglomerate is developed along the shore line of an encroaching sea and occupies many different horizons in the Wassonville.
6. Reworked material from underlying formations is found in the base of the Hampton.
7. The upper surface of the English River is in places leached and covered with solution pits.

In the southeastern province the Wassonville member is unconformably overlain by the Burlington limestone, which overlaps on to the eroded Wassonville surface. The different zones of the Burlington limestone are easily identified and each of these zones in succession from the base upwards may be seen in contact with the Wassonville from Burlington to Wassonville. In the bed of the first creek that enters Iowa river above the Wassonville mill the upper zone of the Upper Burlington limestone may be seen in contact with the Wassonville. In the basin of Long creek, south of Columbus Junction, the green limestone zone that marks the lower part of the Upper Burlington may be seen in contact with the Wassonville. Farther to the south the zones of the Lower Burlington may also be seen in this relation.

The Wassonville increases in thickness correspondingly as the Burlington decreases throughout this distance. At Burlington it is six feet in thickness and to the northwest the thickness gradually increases.

Paleontology and Correlation.—The fauna of the Wassonville cherts has proven to be the most prolific of the entire Hampton formation and it marks a definite horizon that is easily recognized throughout both provinces. The chert fauna is particularly desirable because of the excellent preservation of the fossils found in it.

Fossils are found also throughout the dolomite in which this chert occurs. In the dolomite, however, the fossils are represented only by very poor casts. In the base of the dolomite where much reworked English River grit is found the casts are much better.

Complete Fauna of the Wassonville Member

Zaphrentis cliffordana E. and H.

Platycrinus sp.
Platycrinus sp.
Rhodocrinus sp.

Leptaena analoga (Phillips)
Schellwienella inaequalis (Hall)
Schellwienella planumbona Weller
Schellwienella crenulicostata Weller
Schellwienella inflata (White and Whitfield)
Schellwienella sp.
Streptorhynchus sp.
Chonetes logani Norwood and Pratten
Chonetes illinoisensis Worthen
Chonetes glenparkensis Weller
Chonetes multicostata Winchell
Productus ovatus Hall
Productus arcuatus Hall
Productus sp.
Productella concentrica (Hall)
Rhipidomella thiemei (White)
Schizophoria subelliptica (White and Whitfield)
Schizophoria chouteauensis Weller
Camarotoechia chouteauensis Weller
Camarotoechia tuta (Miller)
Dielasma chouteauensis Weller
Cranaena occidentalis Miller
Rhynchopora pustulosa (White)
Spiriferina solidirostris (White)
Spiriferina subtexta (White)
Spiriferina sp.
Spirifer legrandensis Weller
Spirifer platynotus Weller
Spirifer biplicoides Weller
Spirifer louisianensis Weller
Spirifer sp.
Brachythyris peculiaris (Shumard)
Syringothyris halli (Winchell)
Cliothyridina sp.
Reticularia cooperensis (Swallow)
Eumetria osagensis (Swallow)
Nucleospira barrisi White
Trigeria sp.

Cardiopsis radiata M. and W.
Palaeoneilo barrisi W. and W.
Edmondia jejunus Winchell
Grammysia amygdalinus Winchell
Nucula iowensis Weller
Nucula glenparkensis Weller
Leda sacata (Winchell)
Liopteria subovata M. and G.
Schizodus trigonalis Weller
Schizodus sedaliensis M. and G.
Aviculopecten sp.
Pernopecten cooperensis (Shumard)
Pernopecten sp.

Cypricardinia sulcifera (Winchell)
Sphenotus sp.
Bellerophon blairi Winchell
Bucanopsis perelegans W. and W.
Bucanopsis sp.
Strophostylus bivolve W. and W.
Porcellia sp.
Platyschisma depressa Weller
Straparollus lens Hall
Straparollus macromphalus Winchell
Phanerotinus paradoxus Winchell
Loxonema sp.
Loxonema sp.
Pleurotomaria sp.
Murchisonia sp.
Murchisonia sp.
Euphemus sp.
Euphemus sp.
Worthenia sp.
Warthia sp.
Aclisina sp.
Holopea conica Winchell
Goniatites sp.
Orthoceras indianense Hall
Gyroceras sp.
Dentalium grandaevum Winchell
Proetus sp.

The following fauna was collected from the Wassonville dolomite about eight inches above its contact with the English River at 81 of section 8, Range 8 West, Township 77 North.

Schellwienella crenulicostata Weller
Schellwienella planumbona Weller
Schellwienella inaequalis (Hall)
Schellwienella sp.
Streptorhynchus sp.
Chonetes logani Norwood and Pratten
Chonetes sp.
Productus arcuatus Hall
Productella cf. concentrica (Hall)
Rhipidomella thiemei (White)
Schizophoria subelliptica (W. and W.)
Schizophoria chouteauensis Weller
Spirifer platynotus Weller
Spirifer biplicoides Weller
Spirifer louisianensis Weller
Brachythyris peculiaris (Shumard)
Syringothyris halli (Winchell)
Cliothyridina sp.
Reticularia cooperensis (Swallow)
Nucleospira barrisi White
Edmondia jejunus Winchell
Palaeoneilo barrisi W. and W.
Cardiopsis radiata M. and W.
Elymella missouriensis M. and G.
Pernopecten cooperensis (Shumard)
Sphenotus sp.
Schizodus sp.

Bellerophon blairi Winchell
Bucanopsis perelegans W. and W.
Bucanopsis sp.
Strophostylus bivolve W. and W.
Phanerotinus paradoxus Winchell
Straparollus sp.
Loxonema sp.
Loxonema sp.
Orthoceras sp.
Gyroceras sp.

The Wassonville fauna is very definitely a late Kinderhook fauna. The most common species found in the Wassonville occur also in the Chouteau of Missouri. On the basis of this Chouteau fauna the Wassonville is correlated with some portion of the Chouteau of Missouri.

There are forty species in the Wassonville fauna and of these forty, twenty-two are found in the Chouteau at Newark, Missouri. There are twenty-nine species of brachiopods in the Wassonville fauna and twenty of these are found in the Chouteau at Newark.

The most abundant species in the Wassonville fauna are *Chonetes multicostata, Spirifer platynotus, Productus arcuatus and Straparollus macromphalus.*

Type Sections in Southeastern Iowa

Section of Kinderhook beds at Prospect Hill, Burlington (After Van Tuyl)

		Feet
7.	Limestone, soft, buff to brownish, dolomitic; with casts of fossils; grading up into the lower Burlington limestone	5
6.	Limestone, white, oölitic, scaling off obliquely on weathered surfaces	3
5.	Sandstone, soft, fine-grained, drab weathering buff, shaly in upper part; some seams filled with casts of fossil shells; bearing occasional plant remains	6
4.	Limestone, upper one or two feet brownish and dolomitic. Lower layers consisting of dense gray lithographic-like limestone mottled with small patches of dolomite which in some instances follow small fractures. Small calcite geodes occur in the dolomitic areas, and occasional pockets of sphalerite appear in both the limestone and the dolomite	10
3.	Limestone, lower half coarse-grained and filled with *Chonetes*. Upper half oölitic. Upper surface very undulating, although there is a transition from oölite into limestone above. Contact with bed below in places irregular	⅔
2.	Sandstone, fine-grained, soft, drab weathering buff, massive; with occasional thin intercalated layers of shale; upper two feet filled with casts of fossils, most abundant of which is *Chonopectus fischeri*	22½
1.	Shale, bluish, argillaceous, locally calcareous, drab, sparsely fossiliferous, grading into beds above. The greatest thickness of this bed is in the old clay pit where 19 feet is shown. Between the bed of the pit and the level of Mississippi river, about 14 feet more is concealed. The total thickness of this member at Burlington, as indicated by deep borings, is probably not less than 300 feet. Exposed	19

Section Exposed at Clay Pit, Kalona

		Feet
Wassonville		
4.	Dolomite, brown, fractured, containing one chert band, fossiliferous, basal part containing much reworked English River grit	5
3.	Shale, blue to gray, soft, unctuous, carrying chunks of English River grit. Numerous fish teeth in base	6
English River		
2.	Gritstone, blue to gray, massive, very fossiliferous	5
Maple Mill		
1.	Shale, deep blue to gray, very soft, unctuous, carbonaceous and stained at top, filled with pyrite in lower part, unfossiliferous	14

Section Exposed on South Bank of English River at 81 of section 8, R. 8 W., Twp. 77 N.

Wassonville		
5.	Dolomite, brown, massive, carrying one fossiliferous chert band; gray at base, containing much reworked English River grit. Fossiliferous at base carrying fish teeth and many invertebrates	7
4.	Shale, blue to gray, soft, unctuous, containing chunks of English River grit. Scattered fish teeth	¾
3.	Gritstone, gray to yellow, earthy, discontinuous, undulating on lower surface, crowded with fish remains on its lower surface	½
English River		
2.	Gritstone, reddish in top, gray to blue in lower part, very massive, filled with casts of fossils	15
Maple Mill		
1.	Shale, blue to gray, soft, unctuous, unfossiliferous, filled with lumps of pyrite	12

Section Exposed at the Wassonville Mill

10.	Dolomite, brown, earthy, weathered to a powder, containing fragmented chert and a few large crinoid stems	10
9.	Chert, white, nodular, discontinuous, filled with crinoid stems and many bryozoa	¼
8.	Dolomite, brown to buff, thin-bedded, mottled	8
7.	Chert, white, nodular, discontinuous, very fossiliferous, filled with *Productus arcuatus*	½
6.	Dolomite, brown to buff, very massive	4
5.	Chert, white, nodular, discontinuous, very fossiliferous, filled with *Chonetes multicostata* and many molluscs	½
4.	Dolomite, brown to buff, mixed with brown shale, lower ledge massive	10
3.	Chert, white, hard, nodular, fossiliferous	½
2.	Dolomite, brown to buff, mixed with gray English River material ..	4
English River		
1.	Gritstone, gray to blue, thin-bedded, filled with casts of fossils	10

The North-Central Iowa Province

INTRODUCTION

The Kinderhook of the north-central Iowa province has a considerably different development from that in the southeastern part of the state. The lower portion of the Kinderhook, including the Sweetland Creek, the Maple Mill and the English River formations, is missing in the great part of the northern province.

DISTRIBUTION AND THICKNESS

The entire development of the Kinderhook in the northern province may be assigned to the Hampton formation, with the exception of one small exposure of the English River formation in the southern part of the province in Marshall county.

The Hampton formation reaches a much greater development in the northern central area than in the southeastern part of the state. Its maximum thickness reaches as much as 275 feet. The lower parts of this formation in north-central Iowa correspond roughly to the Hampton of the southeastern province, but the upper part of the Hampton is not represented in the southeastern province.

A complete section of the Hampton formation may not be seen at any one place in the northern province. The lower part is best exposed in Franklin county along Maynes creek, south of Hampton, and the upper members of the formation may be seen along Iowa river in Hardin county, between Eagle City and Alden. By visiting these two localities a complete section of the formation may be seen. Exposures of the Hampton formation may also be seen in the southwest corner of Butler county. The greater part of the western half of Grundy county is underlain by rocks that belong to the Hampton formation, but these are almost entirely obscured by the drift. In the eastern part of Marshall county along Iowa river very good exposures of the lower beds of the formation may be seen.

LITHOLOGIC CHARACTER

The basal member of the Kinderhook of the north-central province consists of hard gray thin bedded fossiliferous limestone that resembles very much the lower gray ledges of the Chouteau at Newark, Missouri.

This basal member contains in its upper part an oölitic member which is occasionally replaced by dolomite.

The next member in the section consists of soft yellow to brown dolomite layers interbedded with much hard flinty chert. This chert is usually white but is occasionally yellow or even black. This member is fairly massive at the base and is more thinly bedded towards the top. The chert bands also are much more numerous near the top.

This cherty dolomite member is followed by a third member, which consists of brown banded limestone, oölitic limestone, massive brown dolomite, hard white lithographic limestone and hard gray oölitic limestone. This third member is very variable in character.

The upper member is of hard massive brown dolomite at the base and thin-bedded dolomite at the top.

STRUCTURE

The Kinderhook rocks of north-central Iowa are essentially horizontal strata. They dip to the southwest with very low slopes that average about 12 feet per mile. Insignificant minor folds are occasionally to be seen along the faces of exposures.

The belt of outcrop is determined roughly by this gentle dip to the southwest. The exposures are mainly limited to the valley walls of the streams, although in Franklin county in a few places the Iowan drift is thin enough to reflect the underlying surface. In this region numerous exposures occur at the tops of the hills as well as in the valley walls of the streams. The exposures are limited on the west by the terminal moraine of the Wisconsin glacier, which obscures practically all bed rock of the region which it covers.

DIVISIONS

With the exception of the exposures of the English River in Marshall and Tama counties, the Kinderhook of the north-central province may all be referred to one formation, in which no large stratigraphic breaks are seen. The fauna carries on through the entire formation with no more striking changes than may be expected within a formation.

In 1922 Van Tuyl[18] divided the northern Kinderhook into six members, the lower of which he called the Sheffield. The Sheffield has now been raised to the rank of formation and correlated with the Chemung

[18] Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 91, 1922.

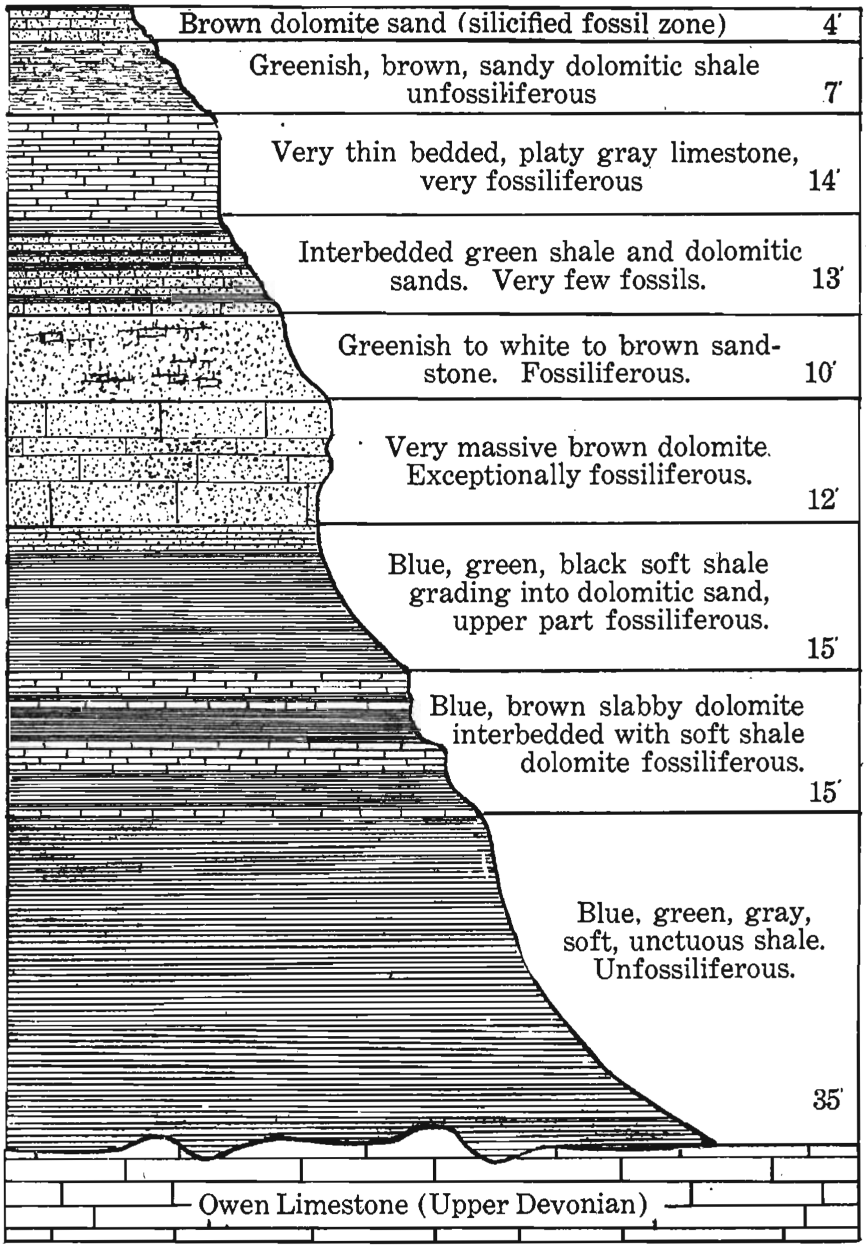

FIG. 51.—Composite Sheffield section as exposed in Franklin county, north-central Iowa.

of New York, which places it in the Upper Devonian. The upper member of the Kinderhook was called the Alden by Van Tuyl. This member has been correlated with the oölitic limestones of Humboldt and Pocahontas counties and is not considered in this paper as Kinderhook. The other members are retained as Van Tuyl used them except for some slight changes in their boundaries.

GENERAL RELATIONS

The Hampton formation lies unconformably upon the Sheffield formation. The Hampton in turn lies unconformably beneath the Alden limestone. There are apparently no beds in the north-central area that may be referred to the Osage. The Burlington limestone is known to pinch out long before it reaches the southern boundary of the province. It seems very likely, however, that much of the material found in the upper members of the Hampton has no equivalent in the Chouteau of Missouri. These upper members are very likely much younger than the latest beds of Chouteau age in Missouri.

THE HAMPTON FORMATION

This name has been proposed for the Kinderhook limestone series exposed in north-central Iowa between the Sheffield formation below and the Alden limestone above. The name Hampton is derived from the city of Hampton, which is the county seat of Franklin county, in which the formation is best exposed. The Hampton formation is divided into four members, the Chapin, the Maynes Creek, the Eagle City and the Iowa Falls, the names of which were proposed by Van Tuyl.[19]

The Chapin Member

As originally defined the Chapin member consisted of about seven feet of brownish oölitic limestone at the base and about eight feet of exceptionally fossiliferous brown dolomite and chert above. The member was described from the Chapin quarry located one mile west of the town of Chapin, in Franklin county. The member at this place rests on the Sheffield formation. Van Tuyl considered this to be the basal part of this limestone series.

Owing to the unconformity at the contact between the Chapin and the Sheffield formation considerable thicknesses of limestone are found in certain places beneath the oölitic member that was originally defined

19 Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 91, 1922.

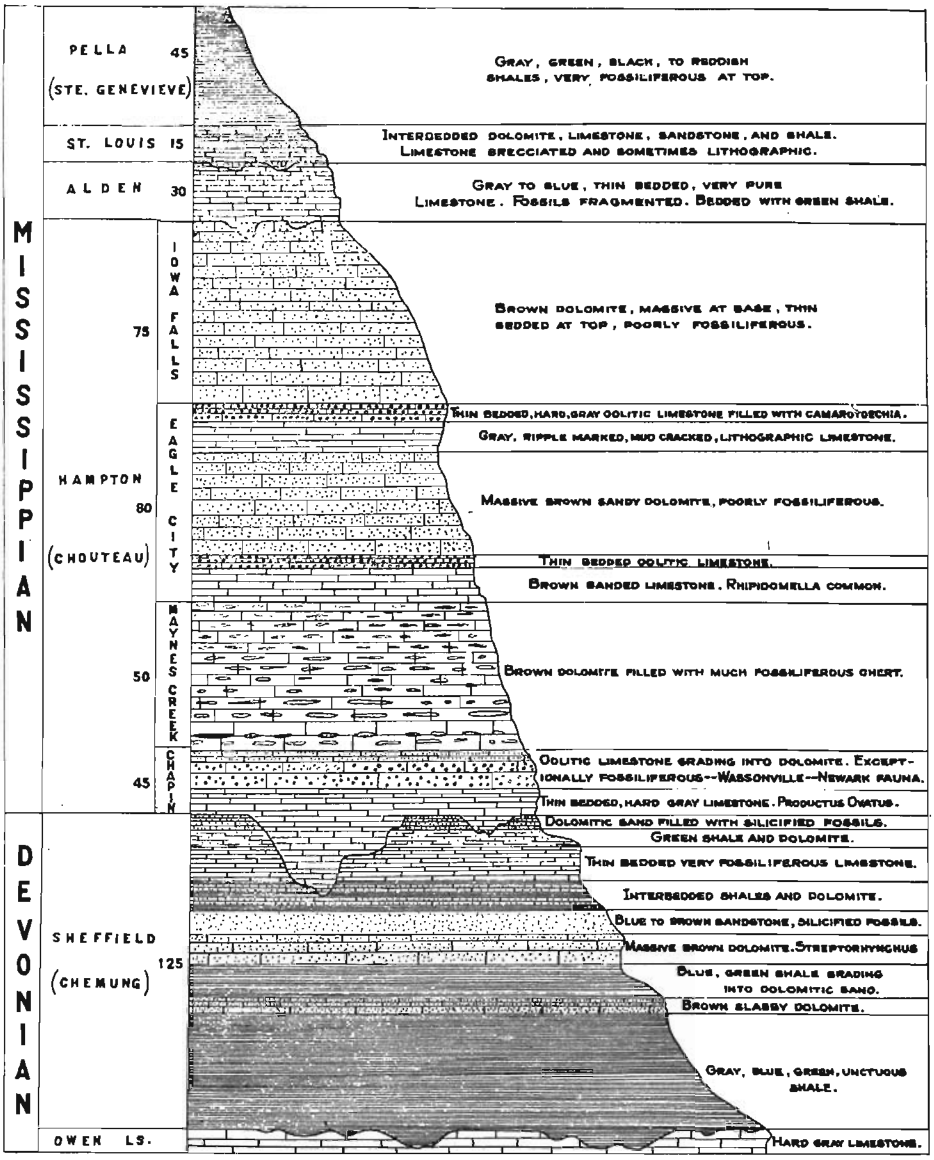

FIG. 52.—Mississippian section of north-central Iowa.

as the base. On Maynes creek to the south of Hampton this limestone reaches a thickness of at least 30 feet.

The fossiliferous brown dolomite that is found in the upper part of the Chapin member as described by Van Tuyl is placed in the base of the Maynes Creek member for these reasons: lithologically and faunally it is almost identical with the overlying Maynes Creek member; it carries the typical Wassonville fauna that marks the base of the Wassonville member in the southeastern province, which is also a dolomite filled with fossiliferous chert; the oölitic limestone member that underlies it is faunally and lithologically like the oölitic limestone that caps the top of the North Hill member in the southeastern province; the gray limestone that forms the base of the member corresponds to the lower part of the North Hill member of the southeastern province; it is a natural break between hard gray limestones beneath and brown chert-filled dolomite above. This makes possible a correlation of member with member.

The oölitic limestone, then, is considered as the top of the Chapin member. It is locally dolomitized but it is always easily separable from the overlying cherty dolomite.

Distribution and Thickness.—The Chapin member is best exposed in Franklin county. The complete section of this member may be worked out only by zone stratigraphy, but at no place in the county may the complete thickness of the member be seen in one section. The maximum section is developed on Maynes creek, which flows through Reeve and Geneva townships, and at all other places only the upper part of the member is exposed. By following Maynes creek from section 14, Geneva township, where the basal portion is exposed, to section 21, Reeve township, where the upper oölitic member is exposed, a complete section may be seen.

The upper oölitic zone is well exposed in the quarry one mile west of the town of Chapin. This quarry is located in the southwest corner of section 29, Ross township. The same zone may be seen in the abandoned quarries at 13, section 24, Mott township.

Several small exposures that probably should be referred to the upper oölitic zone may be seen underlying the Maynes Creek member in the southwestern part of Butler county. The latter exposures are usually very dolomitic and are not fossiliferous.

The member is not seen again until one reaches the southern portion of the province in Marshall county. It comes up to the drift the entire distance across Grundy county but is not exposed at any place. In the Iowa river valley near the town of LeGrand, in the eastern part of Marshall county, and in the adjoining part of Tama county the oölitic

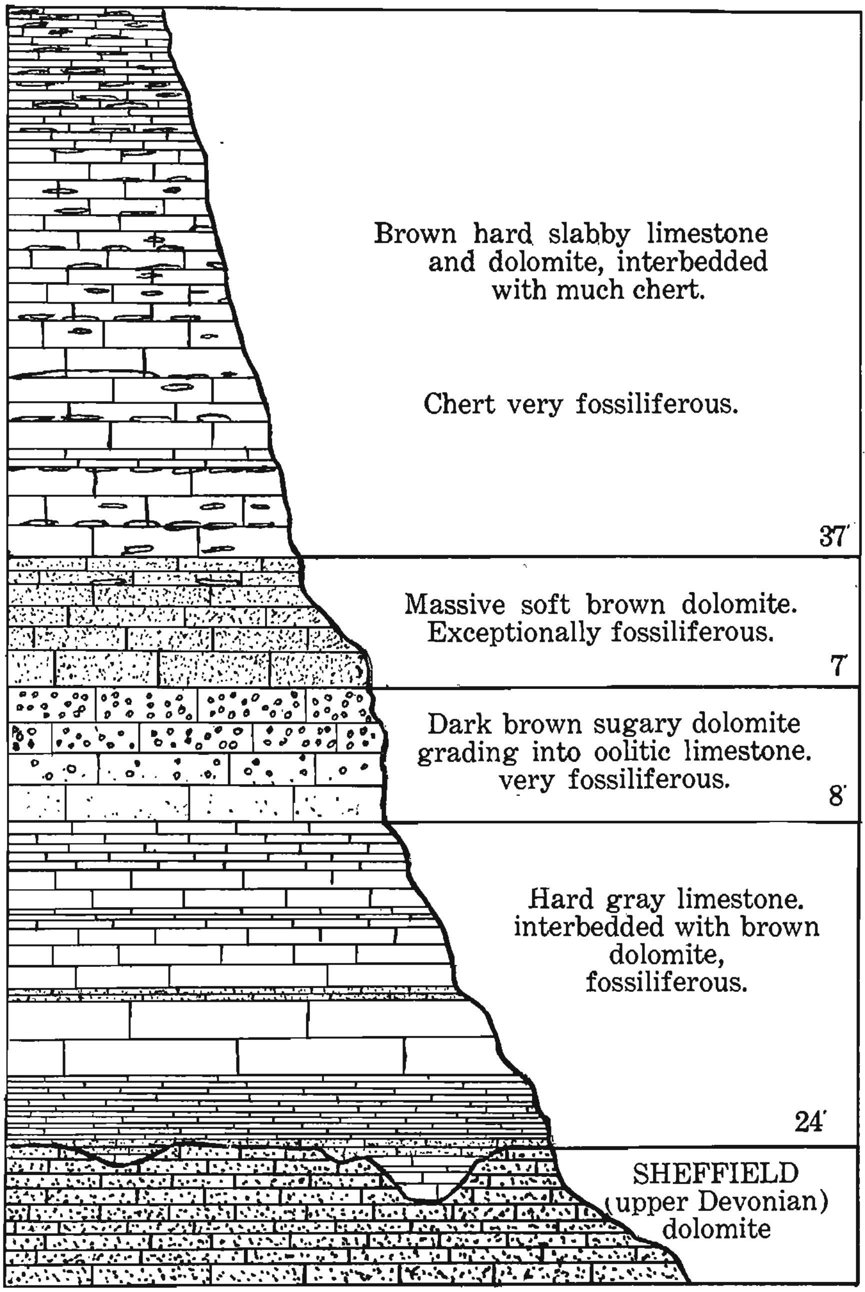

FIG. 53.—Composite section of the Chapin and Maynes Creek members. The upper two groups of beds are referred to the Maynes Creek member.

member is again exposed. At the base of the section, resting unconformably on the English River gritstone, may be seen about 18 feet of hard gray fossiliferous oölitic limestone. This represents the southernmost exposure of the member in the northern province.

The thickness of the member differs by large amounts in short distances because of the unconformable surface on which it rests. In Franklin county it ranges from 45 feet as a maximum to about eight feet at its thinnest development in the Chapin quarry.

Lithologic Character.—Lithologically the member is not a unit although it is almost entirely made up of limestones. The zones within the member are fairly constant with the exception of the upper oölitic portion. It is in places changed to a sugary dark brown dolomite.

Description of the Zones of the Chapin Member

Productus ovatus zone.—The basal zone of the Chapin member is exposed in only one place in the north-central province and marks the lowest portion of the Hampton formation. It consists of about eight feet of very hard gray even-textured fossiliferous limestone layers which resemble the material at the base of the Chouteau section at Newark, Missouri. The limestone is very hard and therefore forms resistant ledges throughout the small area in which it is exposed, that is, in several places throughout the southern half of section 14, Geneva township, notably on the tops of the hills in this area. The drift is so thin that in almost every field the blocks and slabs of this material have been scattered over the surface by cultivation.

Streptorhynchus tenuicostatum zone.—This zone exhibits some lithological variations within itself. It is all of a gray color, however, and is made up entirely of limestone. The basal portion of the zone is made up of very thin beds of hard gray fossiliferous limestone; the central portion consists of alternating layers of the same thin-bedded hard gray limestone and more massive beds of lighter gray limestone that are usually much less fossiliferous; and the upper portion again comprises a series of thin beds. Its dominant color is gray, but many of the beds have considerable amounts of brown dolomitic material in them and the upper layers contain considerable chert. This upper portion is usually rather poorly fossiliferous. The zone is about 25 feet in thickness, and it may be best seen at 69 of section 22, Reeve township, four miles south of Hampton.

Cyathaxonia arcuatus zone.—This zone consists usually of massive hard fossiliferous brown dolomite ledges. In the Chapin quarry, however, it has a tendency to be gray hard oölitic limestone. Where it is oölitic it is easily separated from the overlying dolomitic Maynes Creek member, but when it has been dolomitized its determination is rather difficult without the aid of fossils. It differs from the Maynes Creek in that it is never intercalated with chert bands and is much less fossiliferous. Its ledges are usually much more massive, have a peculiar sugary texture and have a deep chocolate brown color. This zone is best seen in the Chapin quarry one mile west of Chapin, in the southwest corner of section 29, Ross township. Its dolomitic phase may be well studied in an abandoned quarry in the northeast corner of section 23, Mott township.

Paleontology.—The fauna of the basal or *Productus ovatus* zone is not particularly large, but certain species are very abundant throughout. The zone has local distribution hence it is not possible to say how well it retains its faunal unity. Fossils were collected from several exposures in the southern half of section 14, Geneva township, and one very good exposure may be seen on either side of the north-south road about 500 feet south of the center of this section.

Fauna Collected from the Southern Half of Section 14, Geneva Township

Productus ovatus Hall
Productella concentrica (Hall)
Schellwienella sp.
Camarotoechia chouteauensis Weller
Paryphorhynchus elongatum Weller
Syringothyris newarkensis Weller
Grammysia amygdalinus (Winchell)
Capulus paralius W. and W.
Bellerophon blairi M. and G.
Crinoid stem

The zone is especially characterized by the great number of individuals of *Productus ovatus.* This species is not a good index fossil ordinarily because of its long range in the Mississippian. In this particular region, however, it serves very effectively to distinguish the zone. At no other place in the province are large, well preserved individuals found in such abundance.

The fauna of the *Streptorhynchus* zone is considerably larger than that of the underlying zone. Two species, *Streptorhynchus tenuicostatum* and *Spirifer biplicoides,* may be seen on every slab taken from the thin-bedded limestones. The upper part of the zone is not exceptionally fossiliferous, but collections were made from this horizon at several places along Maynes creek. The best exposure may be seen on the south bank of the creek a short distance upstream from the wagon bridge at 69 of section 22, Reeve township.

The lower part of the zone is well exposed on the south bank of Maynes creek, just downstream from the wagon bridge that crosses the creek at 98, section 14, Reeve township.

Fauna of the Streptorhynchus Zone Collected from Various Exposures in Reeve Township

Productus ovatus Hall
Productella concentrica (Hall)
Schellwienella inflata Weller
Streptorhynchus tenuicostatum Weller
Schizophoria chouteauensis Weller
Camarotoechia chouteauensis Weller
Spirifer biplicoides Weller
Spirifer platynotus Weller

The fauna of the *Cyathaxonia arcuatus* zone has been listed by Van Tuyl[20] and a large number of species has been added to his list in this report. Two species, *Cyathaxonia arcuatus* and *Rhipidomella tenuicostata,* are very abundant in the zone. The gray limestones are fossiliferous throughout, but the upper layers contain by far the greater part of the fauna.

Fauna of the Cyathaxonia Zone

(Species marked * were listed by Van Tuyl)

Zaphrentis cliffordana E. and H.
Cyathaxonia arcuatus Weller
Amplexus sp.
Zaphrentis calceola (W. and W.)*
Syringopora sp.
Leptopora typa Winchell
Schizoblastus roemeri (Shumard)
Platycrinus sp.
Leptaena analoga (Phillips)
Chonetes multicostata Winchell
Chonetes logani N. and P.*
Productus arcuatus Hall*
Productus ovatus Hall
Productella concentrica (Hall)
Schellwienella sp.
Schizophoria chouteauensis Weller*
Rhipidomella tenuicostata Weller
Cranaena occidentalis (Miller)
Spiriferina solidirostris (White*)
Spirifer forbesi N. and P.*
Spirifer legrandensis Rowley*
Spirifer platynotus Weller*
Spirifer missouriensis Swallow
Syringothyris newarkensis Weller

20 Van Tuyl, Iowa Geol. Survey, Vol. XXX, p. 105, 1922.

Brachythyris chouteauensis Weller
Athyris crassicardinalis White
Nucleospira barrisi White
Fenestella sp.
Straparollus obtusus (Hall)

Stratigraphy.—The Chapin member lies unconformably on the Sheffield formation throughout the province. Exposures in which the actual contact may be seen are rather few in the region because of the soft nature of the underlying Sheffield formation. In the northern part of Franklin county the upper oölitic zone rests directly on the Sheffield formation. This relation is seen also on Hartgraves creek just east of the city of Hampton. However, when the valley of Maynes creek, to the southeast of Hampton, is reached the lower horizons may be seen. The lowermost beds of the *Productus ovatus* zone are in contact with the Sheffield formation on the south side of the east-west road that runs through the center of section 14, Geneva township, just west of the eastern section line.

In Butler county the actual contact between the two formations is not exposed, and it is doubtful if any part of the Chapin member is present there. The dolomitic Maynes Creek member may be seen in one place and a short distance down Beaver creek the upper dolomites of the Sheffield formation are exposed.

In the extreme southern part of the province this disconformity is exposed again in the contact between the English River gritstone and the Hampton formation which may be seen near LeGrand.

The contact between the Chapin member and the overlying Maynes Creek member is usually marked by an abrupt change in lithology. The gray limestones of the Chapin are replaced immediately by soft massive brown exceptionally fossiliferous ledges of dolomite. At a few places the upper part of the Chapin member has been dolomitized and here the two members grade into each other. The Maynes Creek member, like its equivalent, the Wassonville member, is characterized by its chert bands.

Correlations.—The Chapin member seems to be nearly the exact equivalent of the North Hill member of the southeastern Province, although it is highly probable that the *Productus arcuatus* zone is older than any part of the North Hill member at Burlington. Of the 30 species found in the Chapin member 15 are found in the North Hill member. The *Cyathaxonia arcuatus* or oölitic zone is apparently the equivalent of the oölitic limestone at the base of the section at LeGrand and is also the equivalent of the oölitic limestone or *Schellwienella* zone at Burlington.

The fauna is closely related to that of the Chouteau of Missouri, especially as that fauna is developed in northeastern Missouri. Of the 30 species found in the Chapin member 25 are found in the Chouteau. On the basis of this faunal similarity it seems safe to correlate the Chapin member with the Chouteau of northeastern Missouri. The thickness of the Chapin is slightly greater than that of the Chouteau at Newark.

FIG. 54.—Maynes Creek member at Hampton, showing typical chert bands.

The Maynes Creek Member

The term Maynes Creek was introduced by Van Tuyl[21] in 1922. In it he included 68 feet of brownish fossiliferous dolomite beds interbedded with chert and lying above the dolomite of the Chapin quarry. The type section was located on Maynes creek. The maximum exposure of this member on this creek is located in the northeast corner of section 21, Reeve township, where 41 feet of brown cherty dolomite rests on the upper zone of the Chapin member.

Van Tuyl did not exactly define either the upper or lower limits of the Maynes Creek member. The basal zone of the Maynes Creek as

[21] Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 91, 1922.

defined in this paper was included by Van Tuyl in the Chapin. Several large exposures on Maynes creek in Geneva township which belong mainly to the *Streptorhynchus* zone of the Chapin were referred by Van Tuyl to the Maynes Creek.

The Maynes Creek member is here redefined to include all of the cherty brown dolomitic limestone above the oölitic limestone of the Chapin member and below the banded brown limestone ledges constituting the *Rhipidomella* zone of the Eagle City member. This includes in the Maynes Creek nine feet of cherty brown dolomite that was placed in the Chapin by Van Tuyl and excludes the gray limestones that are found on the lower part of Maynes creek, which apparently belong to the Chapin member. This member at its maximum is only 50 feet thick.

Distribution and thickness.—The basal ledges of the Maynes Creek member form one of the most widespread zones of the Hampton formation. This lower zone, containing the Wassonville-Maynes Creek fauna, may be traced almost continuously across the state. The upper portions of the member are exposed throughout the northern province but are not developed in the southeastern province.

The northernmost exposures of the Maynes Creek formation may be seen in the quarry one mile west of the town of Chapin, in Franklin county. This exposure marks the northernmost outcropping of the Kinderhook in Iowa. The Maynes Creek is also very well exposed along Spring creek in the northwest quarter of section 1, Marion township, and numerous exposures may be seen along Otter creek throughout Mott township.

The best exposures in the region are seen along the south bank of Spring creek in the city of Hampton, where several quarries have been opened. Only the central part of the member is exposed in these abandoned quarries. The upper part of the member is exposed farther up the same creek, however, in the northwest quarter of section 20, Mott township.

The member is well exposed on the upper reaches of Maynes creek in the northwest quarter of section 21, Reeve township. This is the exposure that was designated by Van Tuyl as the type section. Numerous small exposures of the member may be seen along the eastern border of Geneva and Osceola townships, and some good exposures are found a few miles north of the city of Ackley and to the east just across the Butler county line. The lower part of the member is well exposed along the banks of Beaver creek in Butler county in sections 31, 32 and 28 of Washington township. South of Butler county the member is concealed beneath the drift until Marshall county is reached, where a complete section may be seen.

The thickness of the member is rather constant throughout the region, and its maximum may be considered as 50 feet. At no one section in the northern part of the province may the entire thickness of the member be seen.

Lithologic character.—Lithologically the Maynes Creek member is a unit throughout the province. The lithologic character of the Wassonville member of the southeastern province, with which the Maynes Creek is correlated, is the same. The member consists of massive rather soft dark brown dolomitic layers interbedded with numerous bands of white, gray, or, in places, black chert. These chert bands may be continuous over considerable areas or may be in the form of discontinuous nodules. The chert bands are much more abundant in the upper part of the member and consequently the dolomite is much less massive towards the top.

The dolomite consists of many complete rhombohedral crystals, which are dominantly of the silt size, cemented with calcite and limonite. The solubility runs between 85 and 90 per cent. On fresh surfaces the material has more the appearance of brown limestone, but on weathered surfaces it turns to a soft incoherent sand composed of small rhombohedrons of dolomite.

Both the dolomites and the cherts are filled with fossils. Occasionally the chert nodules weather to a soft incoherent body of white powder, and in this case the imbedded fossils are very easily obtainable.

Paleontology.—The Maynes Creek member has been divided into life zones based on associations of fossils, and these zones have been named for the more abundant species which occur in them. Lithology helps only slightly in the differentiation of the zones.

Productus sedaliensis zone.—This zone forms the base of the Maynes Creek member. It consists of about ten feet of massive soft brown dolomite layers in which very little chert is found. This zone contains by far the most abundant fauna of the Maynes Creek member and is the zone from which the main part of the Hampton fauna has been taken. The fossils occur only as casts and moulds in the dolomite and are so abundant that a block six inches in diameter will often yield twenty-five species.

There are several species that might well be used to designate the zone. *Productus sedaliensis* occurs profusely in the zone but is not necessarily the most abundant species. It is used here because it is less abundant in the zone below and does not occur in the overlying zone. Other species such as *Syringothyris newarkensis, Rhipidomella tenuicostata, Leptaena analoga, Spiriferina solidirostris,* a species of *Aorocrinus,* a new species of *Spirifer,* or a new species of *Brachythyris* might very well be used to designate the zone.

Fossils from this zone were first listed by Van Tuyl[22] in 1922. The following list was made at the abandoned quarry a mile west of Chapin, in Franklin county. This exposure should be considered as the type exposure of this zone, since the fauna is best developed and best preserved at this locality.

(Species marked * were listed by Van Tuyl)

Zaphrentis cliffordana E. and H.
Aorocrinus sp.
Cactocrinus sp.
Platycrinus sp.
Cystodictya sp.*
Fenestella sp.*
Orbiculoidea varsoviensis Worthen
Leptaena analoga (Phillips)
Schellwienella crenulicostata Weller
Schellwienella inflata (W. and W.)
Chonetes illinoisensis Worthen
Chonetes glenparkensis Weller
Chonetes logani N. and P.
Chonetes sp.
Productus ovatus Hall
Productus arcuatus Hall*
Productus sedaliensis Weller
Productus sp.
Productella concentrica Hall
Rhipidomella tenuicostata Weller
Schizophoria chouteauensis Weller
Camarotoechia chouteauensis Weller
Cranaena occidentalis (Miller)
Dielasma chouteauensis Weller
Dielasma burlingtonensis (White)
Dielasma sp.
Spiriferina solidirostris (White)
Spiriferina subtexta (White)
Spiriferina sp.
Spirifer stratiformis Meek
Spirifer platynotus Weller
Spirifer biplicoides Weller
Spirifer legrandensis Rowley

22 Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 105, 1922.

Spirifer missouriensis Swallow
Spirifer louisianensis Weller
Spirifer gregeri Weller
Spirifer marshallensis Weller
Spirifer sp.
Brachythyris chouteauensis Weller
Brachythyris sp.
Syringothyris newarkensis Weller
Reticularia cooperensis (Swallow)
Cliothyridina sp.
Eumetria osagensis (Swallow)
Camarophorella lenticularis White
Nucleospira barrisi White
Liopteria subovata M. and G.
Posidonomya sp.
Conocardium sp.*
Cypricardinia sulcifera (Winchell)
Capulus vomerium (Winchell)
Capulus paralius W. and W.
Igoceras undata Winchell
Conularia sp.
Griffithides sp.
Proetus sp.

The *Productus sedaliensis* fauna may be identified at numerous exposures throughout Franklin county, and fossil lists will be given from one or two of the more important exposures.

The fauna of this zone is very well developed in an exposure in the northwest corner of section 24, Mott township. This exposure is in an abandoned quarry about three miles to the northeast of the city of Hampton.

Zaphrentis cliffordana E. and H.
Zaphrentis sp.
Fenestella sp.
Cystodictya sp.
Leptaena analoga (Phillips)
Productus sedaliensis Weller
Productus sp.
Rhipidomella tenuicostata Weller
Schizophoria chouteauensis Weller
Cranaena occidentalis (Miller)
Dielasma sp.
Cyrtina sp.
Spiriferina solidirostris (White)
Spirifer biplicoides Weller
Spirifer legrandensis Rowley
Spirifer platynotus Weller
Spirifer missouriensis Swallow
Spirifer sp.
Eumetria osagensis (Swallow)
Camarophorella lenticularis White
Nucleospira barrisi White
Capulus vomerium (Winchell)
Conularia sp.

The *Productus* zone is also very well exposed along Beaver creek in the southwest part of Butler county. Numerous exposures of the zone may be seen along the valley walls of the creek in sections 31, 32 and 28 of Washington township.

The following fossils were collected from a natural exposure on the south bank of Beaver creek at 43 of section 32, Washington township.

Zaphrentis cliffordana E. and H.
Aorocrinus sp.
Cactocrinus sp.
Platycrinus sp.
Fenestella sp.
Chonetes glenparkensis Weller
Schizophoria chouteauensis Weller
Rhipidomella tenuicostata Weller
Camarotoechia chouteauensis Weller
Paryphorhynchus elongatum Weller
Spiriferina solidirostris (White)
Spiriferina subtexta (White)
Spirifer platynotus Weller
Spirifer missouriensis Swallow
Spirifer striatiformis Meek
Spirifer biplicoides Weller
Spirifer legrandensis Rowley
Spirifer sp.
Spirifer sp.
Syringothyris newarkensis Weller
Brachythyris chouteauensis Weller
Brachythyris sp.
Camarophorella lenticularis White
Athyris crassicardinalis White
Capulus paralius W. and W.
Bellerophon blairi M. and G.
Proetus sp.

Chonetes multicostata zone.—This zone forms the central and main part of the Maynes Creek member. It consists of 25 feet of brown dolomite layers interbedded with numerous bands of gray and white chert. The lower portion of the zone is more massive than the upper portion.

It is in the chert bands that the typical Wassonville-Maynes Creek fauna is found. Most of this chert is very hard and resistant, but at a few horizons is found weathered chert that is filled with fossils. The harder chert bands are filled with fossils also, but it is very difficult to obtain satisfactory material from them. The same fauna is found in the dolomite but occurs only as casts and moulds.

Chonetes multicostata occurs most abundantly in the lower part of the zone. Masses of chert taken from these lower bands are crammed with specimens of this species. These chert masses filled with

Chonetes are found throughout the entire belt of outcrop of the Hampton formation in the state.

Fossils were listed by Van Tuyl in 1922 from this horizon in the northern province. He collected an abundant fauna from the type section of the member on the north bank of Maynes creek in the northwest corner of section 21, Reeve township. At this exposure the cherts are much weathered and the fauna is readily collected. The weathered part at this exposure is only about twelve feet above the bed of the stream.

Fauna from the Type Section

(Species marked * were listed by Van Tuyl)

Zaphrentis cliffordana E. and H.
Cystodictya sp.
Orthotetes sp.*
Chonetes multicostata Winchell
Chonetes illinoisensis Worthen
Chonetes logani N. and P.
Productus ovatus Hall
Productella concentrica (Hall)
Camarotoechia chouteauensis Weller
Camarotoechia tuta (Miller)
Spiriferina solidirostris (White*)
Spirifer legrandensis Weller*
Spirifer platynotus Weller
Nucleospira barrisi White
Tigeria sp.
Leda saccata Winchell*
Myalina sp.*
Liopteria subovata M. and G.
Nucula glenparkensis Weller
Nucula iowensis W. and W.
Straparollus macromphalus Winchell
Bellerophon sp.*
Ducanopsis sp.*
Meekospira sp.*
Orthonychia sp.*
Euphemus sp.
Strophostylus bivolve W. and W.
Proetus sp.
Phillipsia sp.*

In an old quarry on the south bank of Spring creek, in the northern part of the city of Hampton, the cherts of the *Chonetes* zone are again weathered so that the fauna is easily available. This abandoned quarry exposes the entire section of the zone. The following fauna was collected from the lowermost chert band exposed in the quarry.

Zaphrentis cliffordana E. and H.
Chonetes multicostata Winchell
Chonetes illinoisensis Worthen
Schellwienella inflata (W. and W.)
Schellwienella sp.

Productella concentrica (Hall)
Camarotoechia chouteauensis Weller
Camarotoechia tuta Miller
Spiriferina solidirostris (White)
Spiriferina subtexta (White)
Spiriferina sp.
Spirifer platynotus Weller
Spirifer biplicoides Weller
Spirifer sp.
Camarophorella lenticularis White
Nucleospira barrisi White
Tigeria sp.
Ptychodesma sp.
Straparollus macromphalus Winchell
Capulus paralius W. and W.
Orthoceras indianense Hall
Dentalium grandaevum Winchell
Proetus sp.

The two common species in this zone are *Chonetes multicostata* and *Spirifer platynotus*. Both of these species occur throughout this horizon and both of them range in about the same numbers throughout both provinces. The molluscan fauna is not as pronounced in the northern province as it is in the southern.

Spirifer striatiformis zone.—This zone is the uppermost of the Maynes Creek member. It consists of about fifteen feet of thin-bedded yellow dolomite beds that contain much less chert than the underlying zone. As a rule these upper beds are not abundantly fossiliferous. At certain places, however, casts of fossils are found preserved in the soft yellow dolomites.

Exposures of this zone are not numerous in the region. It is exposed in the upper part of the valley of Spring creek, northwest of Hampton, and in the upper valley of Maynes creek, south of Hampton. The fossils where present are preserved as casts in the yellow dolomite. This, however, is of so soft a nature that good specimens are difficult to obtain. It is only in the lower layers that occasional casts of fossils are seen.

The most fossiliferous exposures are seen on the upper reaches of Spring creek, northwest of Hampton. The following species were collected from this horizon at 41 of section 20, Mott township. The top of the *Chonetes* zone may be seen just downstream from the exposure and on the opposite side of the creek.

Zaphrentis cliffordana E. and H.
Platycrinus sp.
Fenestella sp.
Cystodictya sp.

Schellwienella inaequalis (Hall)
Chonetes sp.
Productus sedaliensis Weller
Schizophoria chouteauensis Weller
Spiriferina solidirostris (White)
Spirifer stratiformis Meek
Spirifer platynotus Meek
Brachythyris sp.
Reticularia cooperensis (Swallow)
Proetus sp.

Spirifer striatiformis and Productus sedaliensis occur very abundantly in this zone. The zone may be easily distinguished from the lower zone of the member by the scarcity of fossils.

Stratigraphy.—The Maynes Creek member is separated from the underlying Chapin member only by a slight lithological break. The fauna is directly related to that of the underlying member and continues across the line of contact.

The contact of the Maynes Creek member with the overlying Eagle City member is marked only by a slight lithological break. The rock changes from a soft yellow dolomite to a hard banded crystalline brown limestone which is usually somewhat crinoidal. The contact of the Maynes Creek with the Eagle City is exposed in an abandoned quarry about three and one-half miles north of the city of Ackley, just west of the center of the east line of section 14, Osceola township.

The cherts of the *Chonetes multicostata* zone form such a widespread horizon in Iowa that they may be used for correlation even in well sections a considerable distance west of the belt of exposure.[23] In the main city well No. 8 at Fort Dodge in Webster county the Maynes Creek member with its chert zone is present at 430 feet. In this well indurated rock is struck at 150 feet. The shale and limestone from 150 to 210 feet should be referred to the Pella and St. Louis formations. The oölitic light cream-colored limestone bedded with green shale, from 210 to 310 feet, undoubtedly belongs to the Gilmore City formation of Spergen age. The gray and buff limestones and dolomites from 310 to 430 feet represent the Iowa Falls and Eagle City members of the Hampton formation. From 430 to 480 feet are found brown dolomite and gray cherts which probably represent the Maynes Creek and Chapin members of the Hampton formation. From 480 to 540 feet are shales and yellowish limestones before the true Devonian limestone is reached. Because of the calcareous material

[23] Norton, W. H., Iowa Geol. Survey, Vol. XXI, 1911; Vol. XXXIII, 1927.

which they contain it would seem advisable to refer these shales and limestones to the Sheffield formation rather than to the Kinderhook shales.

In wells farther to the west are found cherts that might possibly be referred to this horizon, although such a correlation would be very uncertain. In the Auburn well in Sac county cherts and brown dolomites are found near the base of the Mississippian section, from 710 to 800 feet. In the Audubon well in Audubon county cherty brown limestone overlying oölitic limestone is found from 955 to 1025 feet.

Correlation.—The fauna of the Maynes Creek member is very definitely related to the Chouteau of Missouri. It is either directly equivalent to some part of the Chouteau or is derived from it. Of the 48 species present in the Maynes Creek member 33 are found in the Chouteau at Newark, Missouri, while 28 are found in the Chouteau of central Missouri.

There are 30 species present in the Chapin member and of these 23 range on into the Maynes Creek. All but one of the 19 species found in the *Chonetes* zone are found in the Wassonville cherts of the southeastern province.

The Eagle City Member

The term Eagle City was introduced by Van Tuyl[24] in 1922. As defined by him it included 70 feet of gray limestones and interbedded dolomite, and its upper limits were very definitely determined. The lower contact was not seen by him in the field and was established only from a deep well section.

The basal member of the Eagle City is a brown banded hard crystalline semicrinoidal limestone about 12 feet thick. The upper part consists of six feet of hard gray very fossiliferous oölitic limestone underlain by 12 feet of hard gray lithographic limestone. The Eagle City member is defined as embracing all strata between and including the banded brown limestone at the base and the oölitic limestone at the top. The central portion of the Eagle City is made up of a massive soft yellow dolomite.

Distribution and Thickness.—The Eagle City member has a very limited distribution in Franklin county, and although it is probably present beneath the drift in a belt extending across the entire county it is exposed only in the southeastern part of the county. The terminal

24 Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 91, 1922.

moraine of the Wisconsin glacier extends across Franklin county in such a manner that the preglacial exposures of the Eagle City member come well within its limits and are deeply buried. This explains the limited number of exposures of the member.

The basal zone of the Eagle City member is exposed in an abandoned quarry about three and one-half miles north of the city of Ackley. This exposure may be seen on either side of the north-south road that runs between sections 13 and 14 of Osceola township. The quarries are located in the west center of section 13 and in the east center of section 14.

The Eagle City formation is not seen again until the valley of Iowa river is reached in Hardin county. Exposures may be seen at many places on either side of Iowa river and in the valleys of small tributary creeks between Eagle City, in the southwest corner of Aetna township, and Iowa Falls, in Hardin township. The last exposures of the member to the west may be seen in the gorge of Iowa river just below the dam at the power plant at Iowa Falls. The dam is built upon the hard lithographic limestones of the upper part of the Eagle City member.

Below Eagle City on Iowa river the exposures are very poor. A few soft dolomitic ledges have been located but it is not possible to refer them to any particular zone. From Steamboat Rock to Eldora the Kinderhook beds are covered by Pennsylvanian sediments. The first outcrop of the Eagle City may be seen on the left bank of Iowa river about a mile south of Eldora. From here on southward occasional exposures may be seen all the way to Marshall county.

The thickness of the Eagle City member is about 80 feet and may be only approximately measured in the field. Each of the separate zones must be measured alone and at different exposures. The lowermost beds may be seen north of Ackley and the remainder may be seen at a series of sections on Iowa river from Eagle City to Iowa Falls.

Lithologic Character.—The Eagle City consists of four rather definite lithological zones. The lowermost is a hard brown banded crystalline partly crinoidal limestone. The second zone consists of very thin-bedded gray oölitic limestone interbedded with fossiliferous dolomite. The main central zone consists of very massive soft brown dolomite beds that reach a thickness of 42 feet. The upper zone consists of two parts, a lithographic limestone at the base and an oölitic limestone at the top. The lithographic limestone is thin-bedded, gray

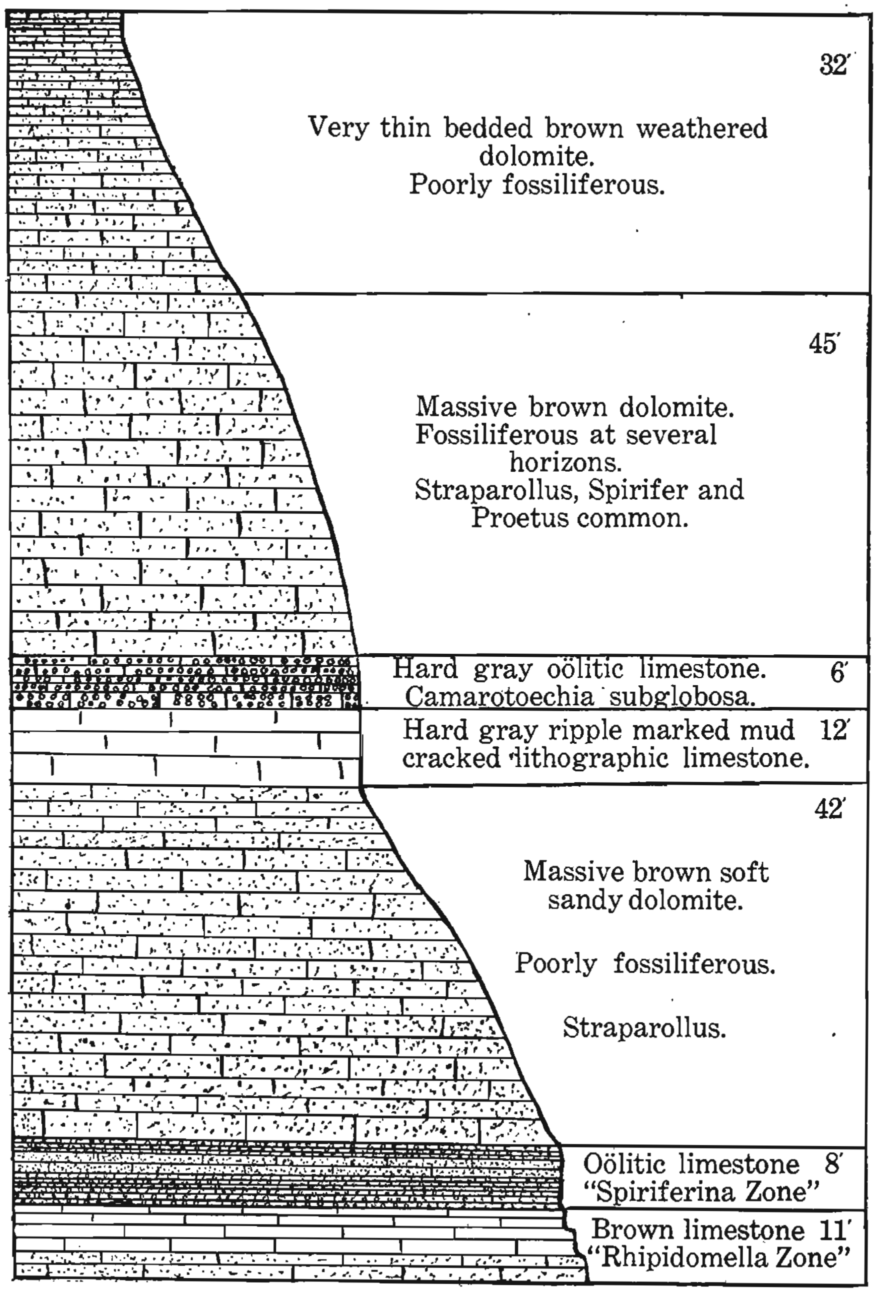

FIG. 55.—Composite section of the Eagle City and Iowa Falls members. The upper two groups of beds are referred to the Iowa Falls.

and slightly ripple marked. The oölite is gray, thin-bedded and very fossiliferous.

The lower part of the Eagle City member may be traced southward and may be seen with the same lithologic character in Marshall and Tama counties. The upper part is exposed only on Iowa river in Hardin county, hence it is not possible to make statements regarding its lithology in other parts of the state.

Paleontology.—The Eagle City member has been divided into four life zones. These zones in this case correspond more or less closely with the lithologic zones. They are named for the most abundant fossils which they contain, although the fauna is not large at any place.

Life Zones of the Eagle City

	Feet
4. *Camarotoechia subglobosa zone*	18
This zone consists of the upper oölitic limestone and the underlying lithographic limestone. The lithographic limestone is almost barren of fossil remains. The upper oölitic part is filled with *Camarotoechia subglobosa.*	
3. *Straparollus obtusus zone*	42
This zone is practically barren of fossils in its greater part. In certain of the beds in the upper part of the zone numerous casts of *Straparollus obtusus* may be found.	
2. *Spirifer biplicoides zone*	8
This is the most fossiliferous zone of the member. It is named for *Spirifer biplicoides,* which occurs very abundantly throughout the zone.	
1. *Rhipidomella burlingtonensis zone*	12
The basal zone is not exceptionally fossiliferous. The banded brown limestone ledges carry a large amount of crinoidal material and numerous specimens of *Rhipidomella burlingtonensis.*	

The *Rhipidomella burlingtonensis* zone is exposed in only one locality, although an equivalent horizon probably is represented in the section at LeGrand in Marshall county. The zone is exposed three and one-half miles north of Ackley, in Franklin county, in the abandoned quarry in the southwest corner of section 13 and in the southeast corner of section 14 of Osceola township.

Fauna of the Rhipidomella Zone North of Ackley

Leptaena analoga (Phillips)
Rhipidomella burlingtonensis Hall
Camarotoechia chouteauensis Weller
Spirifer platynotus Weller
Strophostylus bivolve W. and W.
Cactocrinus sp.
Proetus sp.

The *Spirifer biplicoides* zone outcrops best in the immediate vicinity of the town of Eagle City, in the southwest corner of section 31, Aetna township. The type exposure is located in an old quarry on the east bank of Iowa river just south of the highway bridge that crosses the river at this point. The entire thickness of the *Spirifer biplicoides* zone is exposed at this place, as well as 33 feet of the overlying *Straparollus* zone. The limestones of the *Spirifer biplicoides* zone are exposed along the east bank of Iowa river for a considerable distance downstream from this quarry.

Fauna of the Spirifer biplicoides Zone at Eagle City
(Species marked * were listed by Van Tuyl)

Chaetetes sp.*
Rhombopora sp.*
Fenestella sp.*
Leptaena analoga (Phillips)
Schellwienella inflata Weller*
Streptorhynchus tenuicostatum Weller
Chonetes burlingtonensis Weller
Productus blairi Miller
Productus ovatus Hall*
Productus sp.*
Rhipidomella cf. tenuicostata Weller
Schizophoria sp.*
Camarotoechia chouteauensis Weller
Spiriferina subtexta (White*)
Spiriferina solidirostris (White)
Spiriferina sp.
Spirifer latidor Swallow
Spirifer biplicoides Weller
Spirifer missouriensis Swallow
Spirifer calvini Weller
Eumetria osagensis (Swallow)
Eumetria verneuiliana Hall
Reticularia cooperensis (Swallow)
Hustedia circularis (Miller)
Aviculopecten sp.*
Capulus paralius W. and W.
Orthonychia sp.*
Straparollus sp.*
Orthoceras sp.
Proetus sp.

Beds which may be referred to this horizon are found in the southeastern part of Hardin county in the vicinity of Gifford in Union township. A small exposure of gray-brown limestone may be seen in an abandoned quarry on the south bank of the first small creek south of Gifford on the northeast side of the highway at 77 of section 4, Union township. The following fauna was collected from this exposure.

Schellwienella planumbona Weller
Chonetes logani N. and P.
Camarotoechia chouteauensis Weller
Dielasma chouteauensis Weller
Spiriferina solidirostris White

Spirifer missouriensis Swallow
Spirifer striatiformis Meek
Spirifer platynotus Weller
Reticularia cooperensis (Swallow)
Capulus sp.
Igoceras subplicatum M. and W.

The *Straparollus obtusus* zone forms the greater part of the Eagle City member. The thick massive beds of dolomite exposed along Iowa river between Eagle City and Iowa Falls belong mainly to this zone, but they are very easily confused with the dolomite ledges of the Iowa Falls member. The relation of the *Camarotoechia subglobosa* zone to both the Iowa Falls member and the *Straparollus* zone may be seen in the old quarries along the banks of Iowa river just east of the city of Iowa Falls.

The fauna of the *Straparollus* zone is very meager. Throughout the greater part of this section no traces of fossils may be found. In the central part of the zone is found a thin bed in which casts of *Straparollus obtusus* occur abundantly, with a few other species in association with a cyathophylloid coral and a *Spirifer*. Another layer lower in the section shows numerous stems of a species of *Platycrinus*. The exact horizon of these beds cannot be determined because the contact of neither the underlying nor the overlying zone is exposed.

Fauna collected from an exposure on the south bank of Iowa river at 189 of section 34, R. 20 W., Twp. 89 N.

Zaphrentis sp.
Cyathophyllum sp.
Platycrinus sp.
Spirifer sp.
Straparollus obtusus Hall
Orthoceras cf. indianense Hall

One horizon of the Iowa Falls member also is filled with casts of *Straparollus obtusus*. The Iowa Falls horizon may be easily differentiated from this zone by its greater number of fossils and its greater number of species.

The *Straparollus* zone is again exposed on the right bank of Iowa river one mile south of the city of Eldora. The exposure is about 500 feet downstream from the old highway bridge one mile south of the city. Casts of *Straparollus* and of a cyathophylloid coral are found abundantly in certain beds of the dolomite.

The *Camarotoechia subglobosa* zone consists of two parts lithologically, a hard gray lithographic limestone at the base and a thin-bedded gray oölitic limestone at the top. Both portions are fossiliferous but the number of species present is very limited. Certain horizons of the upper oölitic part are crowded with *Camarotoechia subglobosa.* The next most abundant fossil is a slender cyathophylloid coral.

The zone is best exposed in the Ellsworth stone quarry, located on the left bank of Iowa river just southeast of the city of Iowa Falls at 97 of section 18, Hardin township. The entire zone, with both lower and upper contacts, may be seen here. It is also well exposed in another abandoned quarry just across the river from the Ellsworth quarry. A partial section of the lithographic limestone and the entire oölitic part may be seen in the gorge of Iowa river immediately below the dam at the power plant in Iowa Falls. The exposures of this zone are practically limited to a few miles of the gorge of Iowa river.

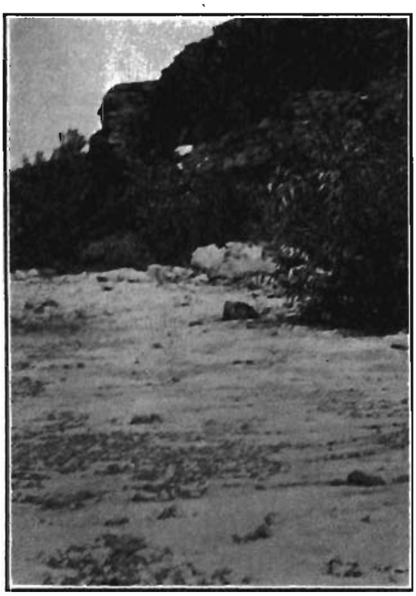

FIG. 56.—Ellsworth Stone Quarry at Iowa Falls. Lithographic limestone forms quarry floor.

Fauna Collected from the Camarotoechia subglobosa Zone
(Species marked * were listed by Van Tuyl)

Cyathophyllum sp.
Syringopora sp.
Stromatopora sp.
Streptorhynchus tenuicostatum Weller
Camarotoechia subglobosa Weller
Camarotoechia sp.*
Eumetria verneuiliana Hall
Conocardium sp.*
Schizodus sp.
Schizodus sp.
Straparollus obtusus Hall

Stratigraphy.—The Eagle City member overlies the Maynes Creek member conformably. The lithologic change from the underlying Maynes Creek dolomite to the brown crystalline limestone ledges of the basal Eagle City is not abrupt. The fauna of the basal Eagle City is definitely related to the Maynes Creek fauna.

The break between the Eagle City member and the overlying Iowa Falls dolomite is sharp, and the gray limestone of the Eagle City ends with knifelike sharpness against the Iowa Falls dolomite. The contact appears irregular and slightly unconformable at all exposures. The lithographic limestone is ripple marked and is undoubtedly of shallow water origin. Oölitic limestone is very likely formed in very shallow water, where the oölites can be intermittently exposed to the air, and such conditions would be found on a tidal flat. The upper surface of the Eagle City is no more uneven than would be expected of a shallow water deposit that had been subjected to the action of waves and shore currents.

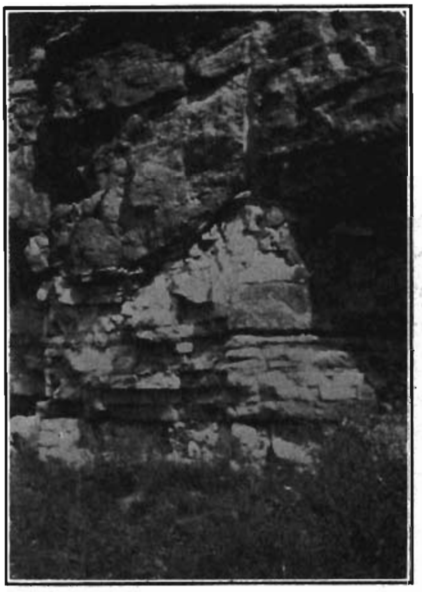

FIG. 57.—Uneven contact of Eagle City with Iowa Falls in Ellsworth Stone Quarry.

Correlation.—The Eagle City member has a very limited distribution. Exposures of the lower zones of the member may be traced southward as far as Marshall county, as for instance near LeGrand in Marshall county, near Conrad and Beaman in southern Grundy county, and around Gifford and Xenia in southern Hardin county. The exposures of the upper part of the zone are confined to Iowa river valley between Eagle City and Iowa Falls.

The fauna of the Eagle City is much smaller than that of the Maynes Creek member but includes many species that undoubtedly were derived from the underlying Maynes Creek. Such forms as *Leptaena analoga, Schellwienella inflata, Streptorynchus tenuicostatum, Camarotoechia chouteauensis, Spirifer missouriensis, Spiriferina solidirostris* and *Spirifer platynotus* are highly characteristic of the underlying members of the Hampton formation.

Such forms as *Eumetria verneuiliana, Productus blairi, Spirifer latior, Spirifer calvini, Hustedia circularis* and *Camarotoechia subglobosa* are not characteristic of the lower members.

There are 29 species of invertebrates present in the Eagle City member and of these 19 are found in the Chouteau at Newark, Missouri, and 16 are found in the Chouteau of central Missouri. The preponderating part of the fauna seems to be related to the Chouteau of Missouri.

Thirteen species that are found in the Eagle City fauna occur in the Osage formations. Such forms as *Camarotoechia subglobosa* and *Eumetria verneuiliana* have never been reported from beds older than the Osage.

The beds of the Eagle City member probably are younger than any of the Chouteau beds of Missouri, but the fauna is definitely derived from the Chouteau fauna. The Eagle City beds are considered to be part of the Hampton formation because their fauna is definitely derived from the Hampton, because of a similarity in lithology with the other members of the Hampton, because of a dissimilarity in lithology between the Eagle City and the Osage beds, and because the Osage beds may be demonstrated to overlap unconformably on the Hampton surface in the southern part of the state.

The Iowa Falls Member

The term Iowa Falls was introduced by Van Tuyl[25] in 1922. The Iowa Falls member as defined by Van Tuyl includes all of the dolomite beds between the oölitic limestone of the Eagle City member and the white limestone ledges of the Alden formation, which overlies the Iowa Falls unconformably. The Iowa Falls member is used in this paper exactly as defined by Van Tuyl.

[25] Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 91, 1922.

Distribution and Thickness.—The Iowa Falls member has a very local distribution, and its exposures are practically confined to a few miles of the Iowa river valley in Hardin county. It undoubtedly underlies extensive areas of this part of the state but is obscured by the heavy drift.

Exposures of the Iowa Falls member may be seen in the bluffs of Iowa river in section 28, Hardin township, where they occupy the upper parts of the bluffs. The member gradually is more and more prominent farther upstream towards Iowa Falls and is best exposed within the city limits, in the gorge of Iowa river above the power plant dam. The lower part is very well exposed in the abandoned stone quarries along Iowa river in the southern part of section 28, Hardin township.

The upper beds are well exposed in the western suburb of Iowa Falls, also at "Wild Cat Glen", along the lower end of Elk run, and along the south bank of Iowa river one mile west of the city in section 14, Range 21 West, Township 89 North. The unconformable contact of the Iowa Falls with the Alden is exposed on the south bank of Iowa river at 79 of section 15, Range 21 West, Township 89 North.

The whole thickness of the Iowa Falls member may not be seen in one section, but it is exposed within the distance of a mile. The lower part may be seen in the gorge above the power plant and the upper thin beds at "Wild Cat Glen", which is less than a mile from the gorge section. The thickness of the member is about 75 feet and may be measured only by projecting known zones over considerable distances.

Lithologic character.—The Iowa Falls member is made up entirely of brown dolomite. It is very difficult to locate exact horizons unless the contact of the Eagle City or of the Alden is exposed. The lower beds are very massive with bedding planes as much as four feet apart. Microscopically the dolomite consists of rhombohedrons of dolomite that are mainly of the silt size and are cemented with calcite. The upper part of the member consists of very thin beds of harder brown dolomite that is usually lighter in color than the lower part. The upper surface, on which the Alden rests, as a rule is very much leached and covered with solution pits. Curious nodular-like masses of harder dolomite are left on this leached surface.

Paleontology.—The Iowa Falls is generally considered to be practically unfossiliferous and the majority of the beds appear as such.

However, at a few localities discontinuous lenses of fossiliferous material have been found.

On the basis of these fossiliferous beds the member has been divided into three zones, but these zones cannot be established with the same definiteness as the zones of the other members of the formation.

Life Zones of the Iowa Falls

Spirifer platynotus zone.—This zone consists of the basal five feet of the member, and at certain localities fossils occur abundantly in the lower three feet. A large form of *Spirifer platynotus* which is really a variety of the true *S. platynotus* characterizes these beds. The association with this *Spirifer* of species that are not found elsewhere in the Hampton definitely establishes the zone.

This zone is exposed in many places near the city of Iowa Falls, but it is only at certain localities that the beds carry fossils. Fossiliferous strata in this horizon may be seen in the old Ellsworth stone quarry on the left bank of Iowa river at 97 of section 18, Hardin township. Fossils may also be collected from this horizon in an old quarry on the left bank of Iowa river about 500 feet downstream from the power plant in Iowa Falls. The following fauna was collected from these two exposures.

Zaphrentis cliffordana E. and H.
Orophocrinus conicus W. and Sp.
Orophocrinus cf. fusiformis W. and Sp.
Orophocrinus cf. stelliformis (O. and Shu.)
Platycrinus sp. 1
Platycrinus sp. 2
Platycrinus sp. 3
Schellwienella sp.
Rhipidomella tenuicostata M. and W.
Rhipidomella burlingtonensis Hall
Productus sedaliensis Weller
Dielasma sp.
Spirifer platynotus Weller
Spirifer missouriensis Swallow
Spirifer biplicoides Weller
Spirifer louisianensis Weller
Spirifer sp.
Reticularia cf. pseudolineata (Hall)
Aviculopecten sp.
Bellerophon blairi M. and G.
Bellerophon sp.
Igoceras subplicatum M. and W.

The Loxonema zone.—This zone is named for an undescribed species of *Loxonema* which occurs abundantly in the horizon. This gastropod is a large easily distinguishable form characteristically about three inches in length. The zone contains an association of species that distinguishes it very readily from any other in the Hampton formation. The fossiliferous part of this zone is about three feet in thickness and is located about 18 feet above the contact of the Eagle City with the Iowa Falls. The *Loxonema* zone is made to include all of the massive dolomite beds above the *Spirifer platynotus* zone. This excludes the upper thin beds of the member and makes the *Loxonema* zone about 40 feet in thickness.

The fossil-bearing beds of this zone may best be seen in the old Ellsworth stone quarry southeast of Iowa Falls, where the fossil-bearing bed occupies a band about five feet down from the top of the quarry face. The zone is well exposed also in the two old stone quarries on the opposite side of Iowa river from the Ellsworth quarry.

The most abundant fossil in the fauna is a large form of *Straparollus obtusus* which averages at least two inches in width. Three species, the *Straparollus*, the *Loxonema*, and a species of *Cyathophyllum* crowd the horizon. The fossils have been preserved for the most part as casts and moulds in the dolomite, but a few have been replaced by a milky white form of calcite.

Fauna Collected from the Loxonema Zone

Cyathophyllum sp.
Cactocrinus sp.
Bryozoa sp.
Streptorhynchus tenuicostatum Weller
Camarotoechia subglobosa Weller
Spiriferina sp.
Spirifer platynotus Weller
Conocardium sp.
Straparollus obtusus Hall
Platyschisma missouriensis Weller
Orthoceras indianense Hall

Centronelloidea rowleyi zone.—The fossils of this zone were collected and listed by Van Tuyl[26] in 1922 and have not been seen by the writer. *Centronelloidea rowleyi* is chosen as a zone name since it is not a common species in other parts of the Kinderhook of Iowa.

The fossils collected from this zone were found in the upper thin beds at "Wild Cat Glen" in the western suburb of Iowa Falls. The upper thin-bedded material is about 30 feet in thickness and only the lower

[26] Van Tuyl, F. M., Iowa Geol. Survey, Vol. XXX, p. 98, 1922.

part of this occurs at "Wild Cat Glen". It is assumed then that these fossils came from the lower part of the zone.

Fauna Listed by Van Tuyl from the Centronelloidea Zone

Zaphrentis sp.
Orthotetes sp.
Dielasma sp.
Camarotoechia cf. tuta (Miller)
Camarotoechia sp. ?
Spiriferina solidirostris (White)
Spirifer sp.
Ambocoelia sp.
Centronelloidea rowleyi (Worthen)
Athyris crassicardinalis White?
Orthonychia sp.
Holopea subconica Winchell?

Stratigraphy.—The Iowa Falls member is separated from the underlying Eagle City member by a sharp lithological break. A discussion of this contact has been given under the stratigraphy of the Eagle City member.

FIG. 58.—Small arch showing contact of Eagle City with Iowa Falls above power plant at Iowa Falls.

The Iowa Falls member is unconformably overlain by the Alden limestone, which consists of soft gray to bluish thin-bedded limestone. The Alden is slightly fossiliferous but the fossils are so fragmented that none have been identified. The Alden is correlated with the oölitic limestone which is exposed near Humboldt and Gilmore City farther to the west. The exact age of the fauna of the Gilmore City limestone is doubtful. The crinoid fauna in the base of the formation at Gilmore City contains a great number of Kinderhook genera although almost all of the species are entirely new. It is considered as younger than the Kinderhook because of the fauna and because of the marked unconformity which separates it from the upper beds of the Kinderhook. The fauna as a whole resembles certain parts of the fauna of the Madison limestone of the west.

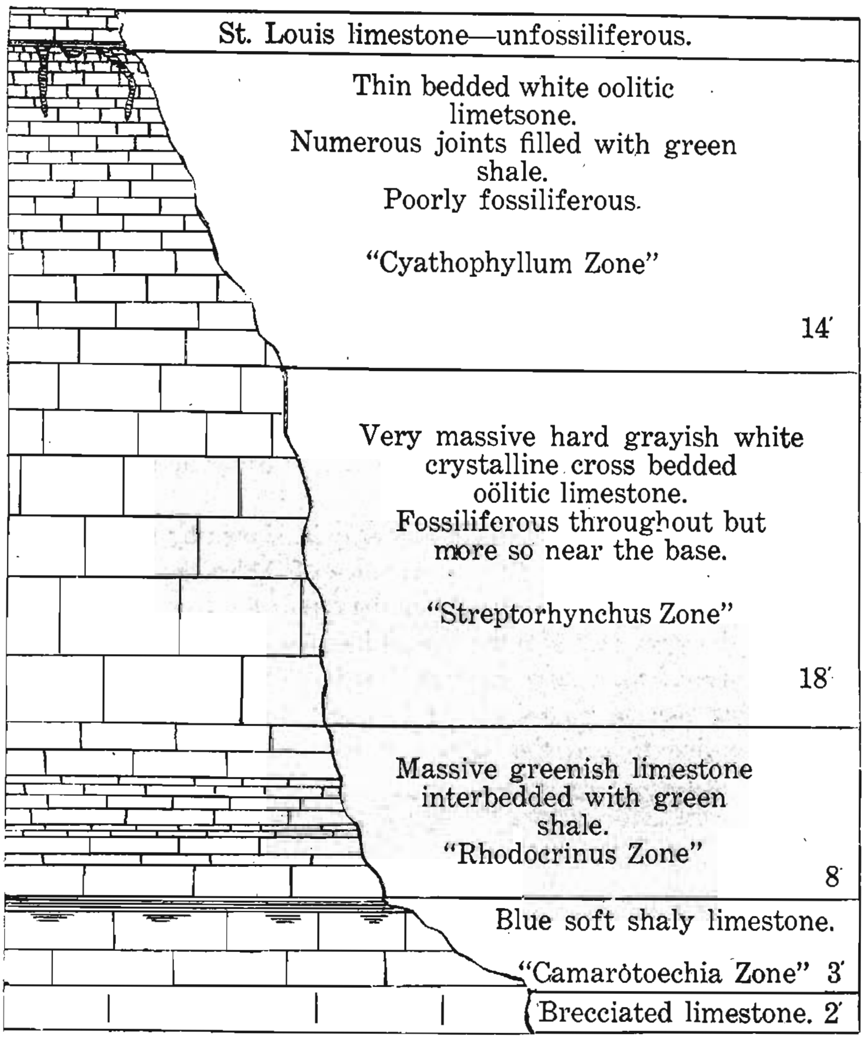

FIG. 59.—Type section of the Gilmore City beds. These beds are exposed in Pocahontas and Humboldt counties and are correlated with the Alden limestone.

The unconformable contact of the Iowa Falls member with the Alden may be seen at several places along Iowa river west of Iowa Falls. The first exposure in which this contact may be seen is located on the right hand bank of Iowa river about 200 feet upstream from the railroad bridge at 39 of section 21, Range 21 West, Township 89 North. Several other exposures of this contact may be seen along the

FIG. 60.—Alden limestone west of Iowa Falls on Iowa river.

river bank in the northern part of section 21. Farther up the river the Iowa Falls is cut out entirely.

The magnitude of this unconformity may be shown by the fact that three miles down Iowa river from the town of Alden the Alden limestone is seen resting unconformably on the top of the Iowa Falls member and at the town of Alden the Iowa Limestone Company has drilled from the base of the quarry through 120 feet of Alden limestone before striking foreign material. At 120 feet the drill penetrated the lithographic limestone of the Eagle City member. The entire 75 feet

FIG. 61.—Alden limestone in the quarry of the Iowa Limestone Company at Alden.

of the Iowa Falls member has been cut out within a distance of three miles.

The Iowa Falls member is not exposed outside of the immediate vicinity of Iowa Falls. Certain thick sections of dolomite in well sections to the west of Iowa Falls are suggestive of the member, but this cannot be definitely determined.

Correlation.—The fauna of the Iowa Falls member is not large enough to allow for many generalizations. A considerable number of the species present were undoubtedly derived from the earlier Hampton fauna. *Spirifer platynotus, Spirifer louisianensis, Spirifer biplicoides, Spirifer missouriensis, Streptorhynchus tenuicostatum, Productus sedaliensis, Rhipidomella tenuicostata, Straparollus obtusus* and *Orthoceras indianense* are all common fossils of the Hampton formation.

There are 20 species in the Iowa Falls member and of these 18 are found elsewhere in the Hampton of Iowa, 12 are found in the Chouteau at Newark, Missouri, and eight in the Chouteau of central Missouri.

Because the strongest faunal relations of the Iowa Falls member seem to be with the underlying Hampton members, and because stratigraphically the Osage beds may be demonstrated to overlap unconformably on to the Hampton surface and to pinch out long before north-central Iowa is reached, and because the lithology of the Iowa Falls does not resemble that of the Osage in any way, the Iowa Falls member is considered to be part of the Hampton formation.

The Iowa Falls member marks the upper limit of the Kinderhook series in Iowa, which at its maximum thickness will total 625 feet. The Maple Mill and English River formations in the southeastern province are 375 feet thick at their maximum development at Burlington, and the Hampton formation is 250 feet thick in the north-central province.

The Hampton Formation at LeGrand

A series of exposures of the Hampton formation may be seen along Iowa river in eastern Marshall county and in western Tama county. A few minor exposures of the formation may be seen in the southern part of Grundy county near Conrad and Beaman, on Wolf creek. Other minor exposures may be seen in the northern central part of Marshall county in the vicinity of Albion and again in the vicinity of

Liscomb. These exposures will be grouped together and described as the LeGrand section.

This group of exposures is located near the town of LeGrand, which is about nine miles east of Marshalltown and is in the heart of the best exposures of the Hampton formation in this region. Several large quarries are now in operation in the vicinity of LeGrand and there are a score of abandoned quarries near the town.

This group of exposures has long been famous for its crinoidal remains. It was in some of these old quarries that Meek and Worthen, Miller and Gurley, R. R. Rowley, Samuel Calvin, and Wachsmuth and Springer first collected the crinoids that have become famous the world over. The LeGrand crinoids have been particularly desirable because of their excellent preservation. These crinoids grew in patches much as a flower garden grows today. Once the main large nest at LeGrand was exhausted it became difficult to find a single good specimen. If one visits the LeGrand quarries it is seldom that more than a badly broken specimen is found. The horizon in which the large nest occurred appears at present to be almost entirely barren. The layers in which the crinoids were found consist of brown soft banded limestone in which it is difficult to find even so much as a crinoid stem. Other nests of these crinoids undoubtedly populated the sea bottom at this time and it seems very likely that others may be uncovered by quarrying operations in the future. The crinoids that grew in this large nest were buried by fine sediments in a condition almost as good as that of the living state. A great number of complete crinoids have been found, complete from the most delicate pinnules on the arms to the cirri on the ends of their stems. A part of the original color of these crinoids is still preserved in the fossil specimens. The original large nest consisted of a lenticular mass of soft slightly magnesian limestone not over one foot in thickness. The edges of this mass pinched down to a few inches in thickness. The crinoids occurred along definite planes within this limestone and often the slabs had to be split to expose the surfaces on which the crinoids lay. The areal extent of this nest was not over fifty by sixty feet. The horizon of the nest was located definitely at 34 feet above the contact of the oölitic limestone with the brown to gray magnesian limestones. This contact may be seen in the quarry from which the crinoids were taken. The horizon from which the crinoids came may now be seen to be a brown soft even-grained banded earthy-appearing slightly magnesian limestone. It may be more definitely located by a close study of the section. In the zone directly below the crinoid horizon there may be seen several layers of brown or blue hard crystalline crinoidal limestone that appear almost identical with many beds that are found in the Burlington limestone. These crinoidal limestone beds are interbedded with softer brown banded limestone beds and occasionally a little chert. The beds from which the crinoids were taken are about three feet above the last of these crinoidal limestone beds.

The quarry from which the crinoids were taken has been reopened and is now (1929) in operation. The face of the quarry has been shifted some 75 feet to the east of the position at which it stood when the crinoids were being removed, and the present quarry floor is located considerably above the position of the old quarry floor. The old quarry penetrated down through the oölitic limestone that forms the base of the formation in this region and the new one has its floor at the top of this oölitic layer or some 18 feet higher. The old quarry hole which penetrated through the oölitic limestone may still be seen at the south end of the present quarry although it is now partly filled with water. This old quarry hole in the oölitic limestone is about 100 feet in length and forms a marker for the nest of crinoids. The heart of the crinoid bed was located about 50 feet up from the northern end and directly to the east of this old quarry hole.

The crinoids of the LeGrand region are not entirely confined to the zone in which the large nest was found. The species that make up the crinoidal limestones in the zone below are for the most part the same species that occur in the large nest. Broken flattened calyces of crinoids that are identical with those found in the upper nests may be collected from these highly crystalline limestone ledges. A few very good specimens showing the arms and stems and calyces have been found on the bedding planes of this lower zone.

The soft gray earthy limestone beds that lie just above the oölitic limestone locally carry small nests that in part resemble the upper nest. The crinoidal association in this lower zone is markedly different from that of the upper one. This lower zone is particularly noted for its abundance of remains of small inadunate crinoids. The crinoids of this lower zone, however, are not confined entirely to these nests, and a few specimens may be expected anywhere within the blocks or on the bedding planes of this limestone. Rows of stems may often be seen protruding from great blocks of this material.

The uppermost beds at LeGrand contain an important amount of fragmented crinoidal material which occurs only as broken or flattened specimens. One species of *Cactocrinus* and several species of *Platycrinus* occur in these upper beds.

The crinoids have been confined for the greater part to the large south quarry. However, a few have been taken from the large north quarry, several from the county quarry on Timber creek, a few from the new quarry on the "Devils Anvil", and several from the abandoned quarries to the west of the large south quarry.

The natural exposures of the material are usually weathered to such an extent that very few fossils may be collected. These limestone beds contain a great amount of dolomitic material which upon weathering appears much like the Wassonville or Maynes Creek members of the Hampton formation.

Distribution and Thickness.—The exposures described under the LeGrand section are confined to Marshall county, the western edge of Tama county, and the southern edge of Grundy county. The main exposures under consideration are within a few miles of the city of LeGrand and most of them are located in the valley of Iowa river.

The thickness of the LeGrand section is about 80 feet and the greater part of this may be seen in continuous sections. The lower oölitic member is usually incompletely exposed in the recently opened quarries. Usually only parts of the upper thin-bedded zone are seen. It is not possible to establish a definite upper limit to the LeGrand beds, although the upper part would be correlated with the lower part of the Eagle City member to the north. The maximum section exposed immediately in the vicinity of LeGrand is about 80 feet.

Lithologic Character.—The LeGrand beds have been divided into life zones and named for the most abundant fossils which they contain.

The Schellwienella planumbona zone.—This zone is named for *Schellwienella planumbona,* which is found abundantly at this horizon. Lithologically it consists of hard gray rather thin-bedded oölitic limestone, which may be easily recognized from other oölitic beds of the LeGrand section by the larger size of its oölites.

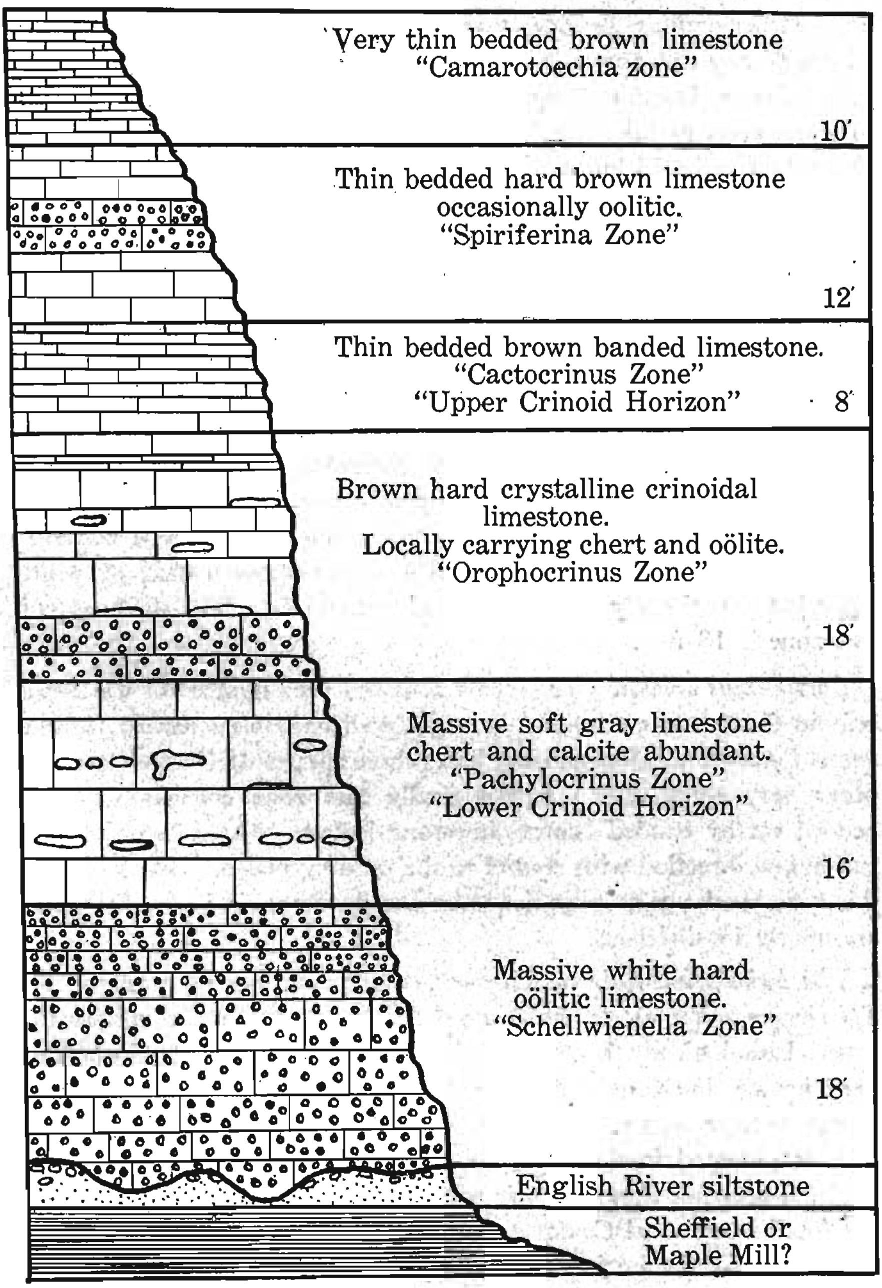

FIG. 62.—Composite section of the LeGrand beds showing life zones.

The Pachylocrinus genista zone.—This zone is named for the crinoid *Pachylocrinus genista,* that is found throughout the horizon. Lithologically this zone consists of very soft earthy gray to yellowish very massive limestone ledges, which contain a large number of gray to white chert nodules filled with *Chonetes multicostata.* The zone is about 18 feet in thickness.

The Orophocrinus conicus zone.—This zone is named for the small blastoid *Orophocrinus conicus,* which may be found at almost any horizon within the zone. Lithologically the zone shows considerable range. The main characteristics by which it may be distinguished are the hard crystalline crinoidal ledges which it contains. These crinoidal ledges are of either a brown or a bluish color and might very easily be confused with ledges of the Burlington limestone. They are interbedded with yellow to brown, either massive or very thin-bedded limestone beds. Locally the basal part of the zone contains a semi-oölitic limestone layer about two feet six inches thick. The zone contains large amounts of nodular chert which is usually of a gray or white color but occasionally may be banded with black. The thickness of this zone is 18 feet.

Cactocrinus arnoldi zone.—This zone has been named for the fossil crinoid *Cactocrinus arnoldi.* It might well have been named for the genus *Cactocrinus* alone since it bears three species of *Cactocrinus* that occur very abundantly. Lithologically this zone consists of thin-bedded earthy banded brown limestone ledges. These brown bands run in any direction with respect to the bedding planes. The layers of this zone break out as large flat slabs usually about six inches thick and are poorly fossiliferous.

The Spiriferina solidirostris zone.—This zone has been named for *Spiriferina solidirostris,* which occurs very commonly throughout the zone. Lithologically the zone consists of very fossiliferous thin-bedded hard brown limestone beds. At several places small beds of oölitic limestone have been seen. Many of the weathered surfaces are matted with fragmented fossils. The zone is about 12 feet in thickness.

Camarotoechia chouteauensis zone.—This zone has been named for the fossil brachiopod *Camarotoechia chouteauensis,* which occurs very abundantly in the horizon. This zone consists of about 10 feet of very thin-bedded brown limestone beds. The average thickness of the individual beds is less than two inches.

Paleontology.—The *Schellwienella planumbona* zone is exposed at many places along the bluffs of Iowa river between LeGrand in Marshall county and Butlerville in Tama county. The best exposure is located at the old mill on the right bank of Iowa river just downstream from the highway bridge that crosses at this point. This exposure is located at 47 of section 1, LeGrand township. The entire section of the zone is exposed here, with both its upper and lower contacts.

Very fossiliferous exposures may be seen on the eastern end of the "Devils Anvil", at 76 of section 7, Indian Village township, Tama county. A small creek cuts through the oölitic member at this point, making each of the beds of the zone easily accessible.

Fauna of the Schellwienella Zone

(Species marked * were listed by Van Tuyl)

Zaphrentis sp.*
Schellwienella inflata Weller
Schellwienella planumbona Weller
Schellwienella sp.*
Chonetes logani N. and P.*
Chonetes burlingtonensis Weller
Chonetes illinoisensis Worthen
Productus ovatus Hall
Productus sp.
Productella sp.*
Productella sp.*
Rhipidomella tenuicostata Weller
Dielasma sp.*
Camarotoechia tuta Miller
Spirifer platynotus Weller
Spirifer sp.*
Syringothyris sp.*
Brachythyris peculiaris (Shumard)
Cliothyridina tenuilineata (Rowley)*
Athyris crassicardinalis White
Composita opposita (W. and W.)
Schizodus sedaliensis M. and G.
Pterinopecten nodocostatus W. and W.
Aviculopecten sp.
Straparollus obtusus (Hall)
Orthoceras sp.*

The *Pachylocrinus* zone is best exposed in the main large south quarry, which is located about a mile and a half north of LeGrand on the right bank of Iowa river at 77 of section 1, LeGrand township. The floor of this quarry is located on the top of the oölitic limestone. The *Pachylocrinus* zone occupies the base of the quarry face. In the extreme southern end of this quarry the old abandoned quarry floor is in the *Pachylocrinus* zone. A large number of the fossils were collected from these old flat weathered surfaces.

The zone is also very well exposed in the county quarry on Timber creek at 97 of section 8, LeGrand township. Here the *Pachylocrinus* zone forms the base of the quarry face as in the south LeGrand quarry. Numerous other exposures might be mentioned, but these two are particularly favorable for a study of the fossils.

Fauna of the Pachylocrinus genista Zone

Cyathaxonia arcuatus Weller
Zaphrentis sp.
Leptopora typa Winchell
Schoenaster legrandensis M. and G.
Archaeocidaris legrandensis M. and G.
Pachylocrinus genista M. and G.
Rhodocrinus watersianus W. and Sp.
Platycrinus symmetricus W. and Sp.
Dichocrinus delicatus W. and Sp.
Leptaena analoga (Phillips)
Schellwienella sp.
Chonetes multicostata Winchell
Productus ovatus Hall
Productus arcuatus Hall
Productus sp.
Productus sp.
Productella concentrica (Hall)
Rhipidomella dubia Hall
Rhipidomella thiemei White
Camarotoechia tuta Miller
Camarotoechia chouteauensis Weller
Rhynchopora pustulosa (White)
Spirifer platynotus Weller
Spirifer louisianensis Weller
Spirifer missouriensis Swallow
Cliothyridina incrassata Hall
Eumetria sp.
Platyceras erectoides Weller

This zone will correspond very closely with the Wassonville cherts and the base of the Maynes Creek member. At all three places it is characterized by nodules of chert filled with *Chonetes multicostata.* The small form of *Leptaena analoga* which occurs abundantly in the Wassonville is also found in this zone. It is also especially crowded with the remains of small inadunate crinoids, several of which belong to the genus *Pachylocrinus.* This is the lowest horizon in which the crinoids are found in nests.

The *Orophocrinus* zone is very well exposed in several places near LeGrand, the best of which is probably in the south quarry. This zone forms the central part of the face for the entire length of the quarry.

The zone is also well exposed in the north quarry on the opposite side of Iowa river. Very fossiliferous ledges belonging to this zone may also be seen in the county quarry on Timber creek. An exceptionally fossiliferous part of this zone is exposed in the floor of an old abandoned quarry about 500 feet to the west of the south end of the large south quarry at LeGrand.

The fauna of the zone comes mainly from the crinoidal ledges. The major part of it comes from the bedding planes at the top of these ledges and a smaller part from within these ledges. About three feet of very fossiliferous semi-oölitic limestone occurs in this zone in the county quarry on Timber creek.

Fauna of the Orophocrinus conicus Zone

Zaphrentis cliffordana E. and H.
Zaphrentis wortheni Weller
Cyathaxonia arcuatus Weller
Leptopora typa Winchell
Orophocrinus conicus W. and Sp.
Orophocrinus fusiformis W. and Sp.
Orophocrinus stelliformis (O. and Shu.)
Eutaxocrinus fletcheri (Worthen)
Rhodocrinus watersianus W. and Sp.
Megistocrinus nobilis W. and Sp.
Aorocrinus immaturus W. and Sp.
Cactocrinus arnoldi W. and Sp.
Platycrinus sp.
Platycrinus sp.
Dichocrinus sp.
Agelacrinus legrandensis M. and G.
Leptaena analoga Phillips
Schellwienella inflata Weller
Schellwienella planumbona Weller
Schellwienella inaequalis Weller
Streptorhynchus sp.
Productus arcuatus Hall
Productella concentrica (Hall)
Rhipidomella burlingtonensis Hall
Schizophoria sedaliensis Weller
Cranaena sp.
Dielasma chouteauensis Weller
Dielasma sp.
Camarotoechia chouteauensis Weller
Spiriferina solidirostris (White)
Spiriferina sp.
Spirifer biplicoides Weller
Spirifer platynotus Weller
Spirifer gregeri Weller
Spirifer legrandensis Rowley
Spirifer calvini Weller
Spirifer louisianensis Weller
Spirifer sp.
Brachythyris chouteauensis Weller
Cliothyridina sp.
Athyris crassicardinalis White

Bellerophon blairi M. and G.
Igoceras subplicatum M. and W.
Capulus piso Walcott
Capulus paralius W. and W.
Strophostylus bivolve W. and W.

Proetus sp.
Griffithides sp.

Fish tooth, 1.
Fish tooth, 2.
Fish tooth, 3.
Fish tooth, 4.

The *Cactocrinus* zone is well exposed in both the north and south quarries at LeGrand. It may be easily identified in nearly all of the abandoned quarries in the region. Lithologically it consists of rather thin-bedded soft earthy banded limestone ledges in which the bands run with no apparent relation to the bedding planes.

The zone is characteristically poorly fossiliferous, with ledges appearing almost barren. The fossils that are found in this zone are very well preserved, suggesting a period of rapid sedimentation in relatively quiet waters. The large LeGrand crinoid fauna was taken from the lower ledges of this zone.

Fauna of the Cactocrinus arnoldi Zone

Orophocrinus conicus W. and Sp.
Orophocrinus fusiformis W. and Sp.

Archaeocidaris legrandensis M. and G.

Rhodocrinus kirbyi W. and Sp.
Rhodocrinus nanus M. and G.
Rhodocrinus watersianus W. and Sp.
Megistocrinus nobilis W. and Sp.
Batocrinus macbridei W. and Sp.
Batocrinus poculum M. and G.
Aorocrinus parvibasis W. and Sp.
Aorocrinus immaturus W. and Sp.
Aorocrinus radiatus W. and Sp.
Cactocrinus ornatissimus W. and Sp.
Cactocrinus nodobrachiatus W. and Sp.
Cactocrinus arnoldi W. and Sp.
Platycrinus symmetricus W. and Sp.
Platycrinus agassizi W. and Sp.
Dichocrinus inornatus W. and Sp.
Dichocrinus delicatus W. and Sp.
Dichocrinus cinctus M. and G.
Eutaxocrinus fletcheri (Worthen)
Taxocrinus intermedius W. and Sp.
Pachylocrinus scopae (M. and G.)
Pachylocrinus genista (M. and G.)
Pachylocrinus elegantulus (W. and Sp.)
Pachylocrinus globosus (W. and Sp.)
Pachylocrinus legrandensis (M. and G.)
Pachylocrinus spartarius (M. and G.)
Goniocrinus sculptilis M. and G.
Decadocrinus maccabei (M. and G.)

Decadocrinus hammondi (M. and G.)
Decadocrinus decrepitus (M. and G.)
Decadocrinus longicirrifer (W. and Sp.)
Woodocrinus notatus (M. and G.)
Productus ovatus Hall
Productus sp.
Productus sp.
Schellwienella planumbona Weller
Fish tooth

The *Spiriferina* zone forms the upper part of the quarry faces in both of the large LeGrand quarries. It is also well exposed at the "Devils Anvil" in Tama county. The zone consists of hard brown thin beds of highly fossiliferous limestone. These beds are much more fossiliferous than any other part of the LeGrand section, but the fossils are much fragmented. Some of the slabs from this zone are made up entirely of masses of *Spiriferina solidirostris. Spirifer platynotus. Rhipidomella dubia,* and an undescribed form of *Cactocrinus* occur very abundantly in the zone.

Fauna of the Spiriferina solidirostris Zone

Zaphrentis cliffordana E. and H.
Leptopora typa Winchell
Orophocrinus conicus W. and Sp.
Schizoblastus sp.
Platycrinus sp.
Platycrinus sp.
Cactocrinus sp.
Rhipidomella dubia Hall
Camarotoechia chouteauensis Weller
Spirifer platynotus Weller
Spirifer sp.
Spiriferina solidirostris (White)
Athyris crassicardinalis White
Bellerophon blairi M. and G.
Straparollus missouriensis M. and G.
Orthoceras sp.
Orthoceras sp.
Fish tooth.

The *Camarotoechia* zone is not exposed in either of the two main quarries at LeGrand. It may be seen only on the small tributaries of Iowa river farther back from the main stream where erosion has not removed the beds. The zone is best exposed at Rockton at 88 of section 21, Range 17 West, Township 84 North, and it is also well exposed in the bluffs of the small tributary that enters Iowa river in the south-central part of section 36, two miles north of LeGrand. The zone is also exposed on Wolf creek, in the vicinity of Conrad and Beaman, in the southern part of Grundy county.

The ledges of this zone are not exceptionally fossiliferous but certain beds are filled with *Camarotoechia chouteauensis* and several species of *Schellwienella.*

Fauna of the Camarotoechia chouteauensis Zone

Orophocrinus conicus W. and Sp.
Schellwienella crenulicostata Weller
Schellwienella planumbona Weller
Schellwienella sp.
Schellwienella sp.
Productella concentrica (Hall)
Schizophoria sp.
Rhipidomella sp.
Cranaena sp.
Rhynchotreta sp.
Camarotoechia chouteauensis Weller
Spiriferina solidirostris (White)
Spirifer legrandensis Weller
Straparollus obtusus (Hall)
Conularia sp.

Stratigraphy.—The LeGrand beds overlie the English River formation unconformably. Only one of the exposures beneath the LeGrand beds carries a fauna and this fauna belongs definitely to the English River formation. It is highly probable that over the greater part of this area the LeGrand beds lie unconformably on the Sheffield formation. The exposure at the old mill one mile north of LeGrand has more the appearance of Sheffield material than of English River. It is not possible to determine definitely to which of these formations it should be referred because of the lack of fossils.

The LeGrand beds probably grade conformably into beds that would be correlated with the basal part of the Eagle City member. The actual contacts are not exposed but probably exist farther to the north where the Eagle City material has not been removed by erosion.

Correlation.—The *Schellwienella* zone of the LeGrand beds is correlated with the upper part of the Chapin member of the north-central province and with the upper part of the North Hill member of the southeastern province. The fauna is almost identical with that of the *Schellwienella* zone of the North Hill member.

The *Pachylocrinus* and *Orophocrinus* zones are correlated with the Wassonville member of the southeastern province. The chert bands present in the LeGrand at this horizon have the typical Wassonville fauna present.

The *Pachylocrinus, Orophocrinus, Cactocrinus* and *Spiriferina* zones are correlated with the Maynes Creek member of the north-central province. It is difficult to draw the exact line betweeen the portion of the LeGrand beds that should be referred to the Eagle City and the portion that should be referred to the Maynes Creek. The lower two zones of the LeGrand undoubtedly correspond to the lower cherty part of the Maynes Creek.

The *Camarotoechia* zone is correlated with the lower oölitic limestone of the Eagle City member. Lithologically and faunally these zones are much alike.

Type Sections in North-central Iowa

Section Exposed in Old Quarry One Mile West of Chapin

	Feet	Inches
6. *Dolomite,* thin-bedded, soft, yellowish, very fossiliferous, filled with irregular masses of gray and black chert	3	6
5. *Dolomite,* massive, moderately hard, dark brown, filled with casts of fossils	2	4
4. *Dolomite sand,* soft, granular, yellow, very fossiliferous		6
3. *Limestone,* gray to brown, slightly crinoidal, oölitic in part, massive, filled with fossils. *Schizoblastus roemeri, Cyathaxonia arcuatus*	2	4
2. Limestone, gray, oölitic, hard, massive, slightly fossiliferous	2	6
1. Dolomite, massive, dark chocolate brown, hard, slightly crinoidal, banded, fossiliferous	3	

Beds 1, 2 and 3 are referred to the Chapin member and beds 4, 5 and 6 to the Maynes Creek member. Beds 5 and 6 carry the main part of the fauna that has been listed from the *Productus sedaliensis* zone.

Section showing the lower beds of the Chapin member exposed on the south bank of Maynes Creek at 67 of section 22, Reeve township, Franklin county.

	Feet	Inches
7. *Limestone,* very thin-bedded, brown to gray, dolomitic at top, carrying much chert, slightly fossiliferous	9	
6. *Shale,* brown, earthy, irregular contact above and below. Products of disintegrated limestone	1	
5. *Dolomite,* thin-bedded, brown, fairly hard, a little brown chert, poorly fossiliferous	4	
4. *Limestone,* hard, brown, dolomitic, poorly bedded, fractured, unfossiliferous	5	4
3. *Limestone,* very hard, chunky, white, semi-oölitic, irregular bedding, fossiliferous	4	
2. *Limestone,* massive, hard, brown, fossiliferous	2	8
1. *Limestone,* thin-bedded, hard, brown, slabby, crinoidal, very fossiliferous	3	2

The entire section is referred to the *Streptorhynchus tenuicostatum* zone of the Chapin member.

The following exposure of the *Chonetes multicostata* zone of the Maynes Creek member may be seen in an old quarry on the east bank of Spring creek just north of the city of Hampton in Franklin county.

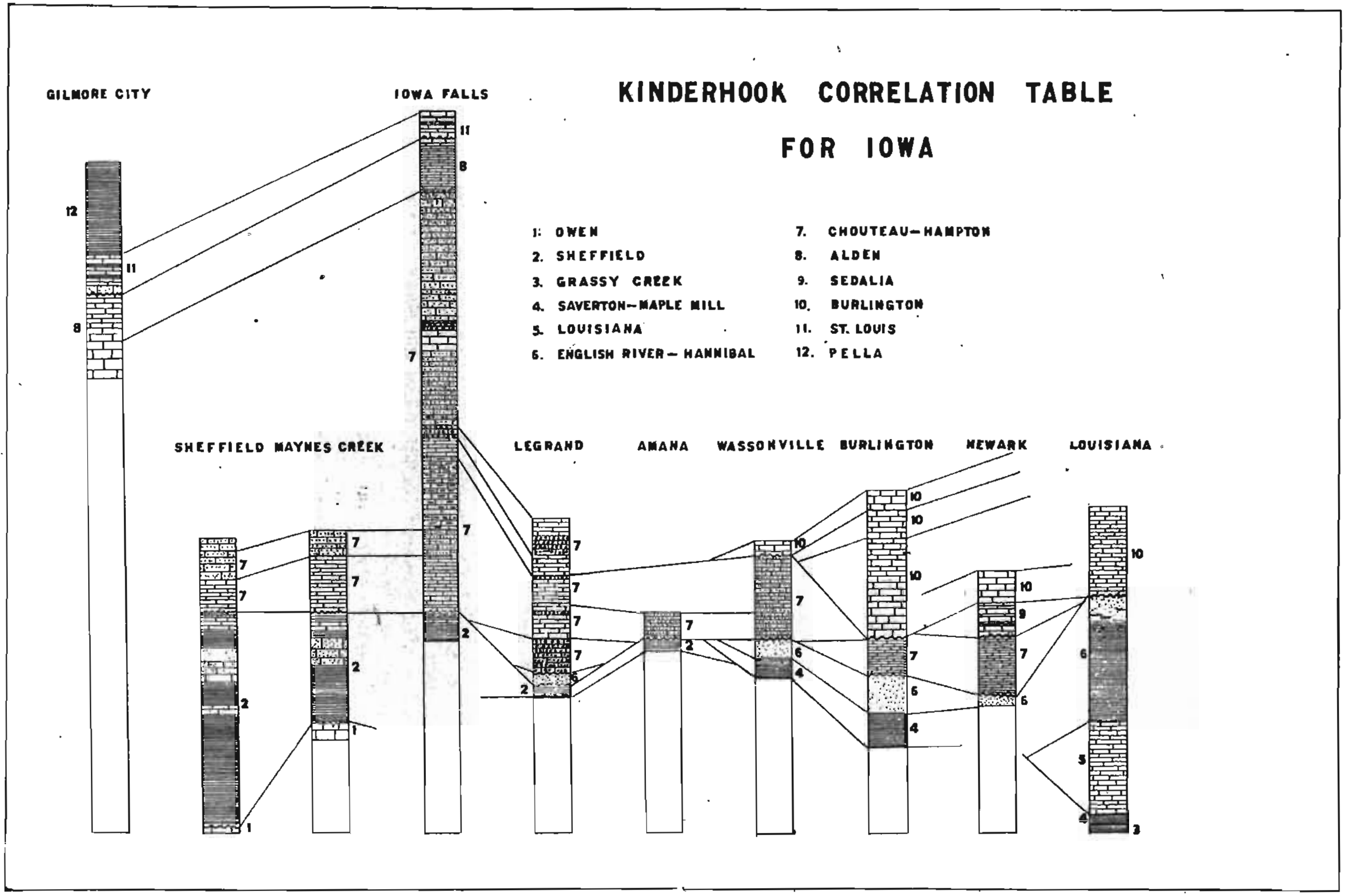

FIG. 63.—Kinderhook correlation chart showing the thick section of the Hampton formation at Iowa Falls and emphasizing the unconformity at the base of the Hampton formation. Scale: 1 inch equals 100 feet.

		Feet	Inches
7.	*Dolomite,* thin-bedded, soft, brown, interbedded with much brownish gray fossiliferous chert	4	3
6.	*Dolomite,* hard, brown, more massive than underlying and overlying beds	2	3
5.	*Dolomite* and *chert,* thin-bedded, brown, interbedded with hard brown to gray fossiliferous chert	4	
4.	*Chert,* hard, fractured, slightly banded, brown to white, fossiliferous		10
3.	Dolomite, massive, yellow to brown, poorly fossiliferous	3	6
2.	*Chert,* yellowish to white, soft, filled with fossils. *Chonetes multicostata, Spirifer platynotus* and *Camarotoechia chouteauensis*		3
1.	*Dolomite,* massive, brown to yellow, interbedded with fossiliferous white chert in bands and in nodules	8	

This section of the *Rhipidomella* zone of the Eagle City member is exposed in an old quarry three miles north of Ackley at 444 of section 13, Osceola township.

		Feet
3.	*Limestone,* thin-bedded, hard, slightly oölitic, crinoidal in part, fossiliferous	3
2.	*Limestone,* massive, brown, hard, banded, crinoidal. Filled with *Rhipidomella burlingtonensis*	1⅝
1.	*Limestone,* thin-bedded, slightly oölitic, gray to brown, partly crinoidal	4

The following Eagle City exposure is located just south of the highway bridge at Eagle City in an abandoned quarry. This is the type section of Van Tuyl.

		Feet
8.	*Dolomite,* thin-bedded, slabby, yellow to brown, contains a few chert nodules and one or two beds of hard dark brown dolomite	8
7.	*Dolomite,* massive, very soft, yellow, unfossiliferous	8
6.	*Dolomite,* thin-bedded, soft, sandy, carrying a little chert. Upper part appears to be a replaced oölitic limestone	10
5.	*Dolomite,* brownish, porous, possibly once oölitic, very fossiliferous	3
4.	*Dolomite,* chocolate brown, bedding planes about 8 inches apart, unfossiliferous	5
3.	*Limestone,* thin-bedded, gray, oölitic, fractured, very fossiliferous	1½
2.	*Dolomite,* massive in upper part, thin-bedded below, dark brown, unfossiliferous	3
1.	*Limestone,* thin-bedded, gray to white, slightly oölitic, very fossiliferous	3

The lower five beds are referred to the *Spirifer biplicoides* zone and the upper three to the *Straparollus* zone.

The following section of the upper part of the Eagle City member and the lower part of the Iowa Falls member is exposed in the Ellsworth stone quarry on the left bank of Iowa river in Iowa Falls.

		Feet
9.	*Dolomite,* thin-bedded, soft, sandy, coarse-grained, unfossiliferous	5
8.	*Dolomite,* brown, soft, sandy, thin-bedded, filled with casts of *Straparollus obtusus* and a simple coral. A *Loxonema,* a *Conocardium* and a *Spirifer* are also quite abundant	8
7.	*Dolomite,* fairly massive, chocolate brown, soft, containing calcite nodules, interbedded with green, red and brown shaly material	11

	Feet
6. *Dolomite*, hard, porous, dark brown, contains calcite nodules, many casts of fossils, *Spirifer platynotus*, *Rhipidomella burlingtonensis* and a *Reticularia*	2
5. *Shale*, soft, yellowish, gray, blue, containing considerable limonite and calcite, rests on rather uneven surface of oölitic limestone	⅔
4. *Limestone*, hard, thin-bedded, white to gray, oölitic, much fractured, stylolites, veins of calcite, filled with *Camarotoechia subglobosa*	5⅝
3. *Limestone*, dense, hard, white to gray, lithographic, ripple-marked, thin-bedded, poorly fossiliferous. Contains two dolomite beds. Stromatoporoids common	12
2. *Dolomite*, massive, brown, filled with large masses of calcite. Pyrite, siderite and dolomite crystals locally	6½
1. *Dolomite*, very massive, dark brown, banded, very hard, unfossiliferous	7

Beds 1 and 2 are referred to the *Straparollus* zone of the Eagle City member. Beds 3 and 4 are referred to the *Camarotoechia subglobosa* zone of the Eagle City. Beds 5 and 6 are referred to the *Spirifer platynotus* zone of the Iowa Falls member. Beds 7, 8 and 9 are referred to the *Loxonema* zone of the Iowa Falls member.

The following section shows the upper part of the Iowa Falls member and the lower part of the Alden limestone and is exposed in the old Ivanhoe quarry at 73 of section 16, Range 21 West, Township 89 North.

	Feet
4. *Limestone*, thin-bedded, soft, cream-colored to bluish, bedded with green shale, slightly crinoidal, containing very much fragmented fossils. Some portions slightly oölitic	14
3. *Limestone*, massive, soft, cream-colored, filled with crinoidal fragments	2
2. *Limestone*, hard, massive, brown to blue, partly crinoidal. Fish tooth. Rests on very uneven weathered surface of Iowa Falls dolomite	4
1. *Dolomite*, thin-bedded, brown, highly weathered, surface irregular, covered with solution pits. Nodular-like masses of hard dolomite left on surface	4

Bed 1 is referred to the Iowa Falls member. Beds 2, 3 and 4 are referred to the Alden limestone.

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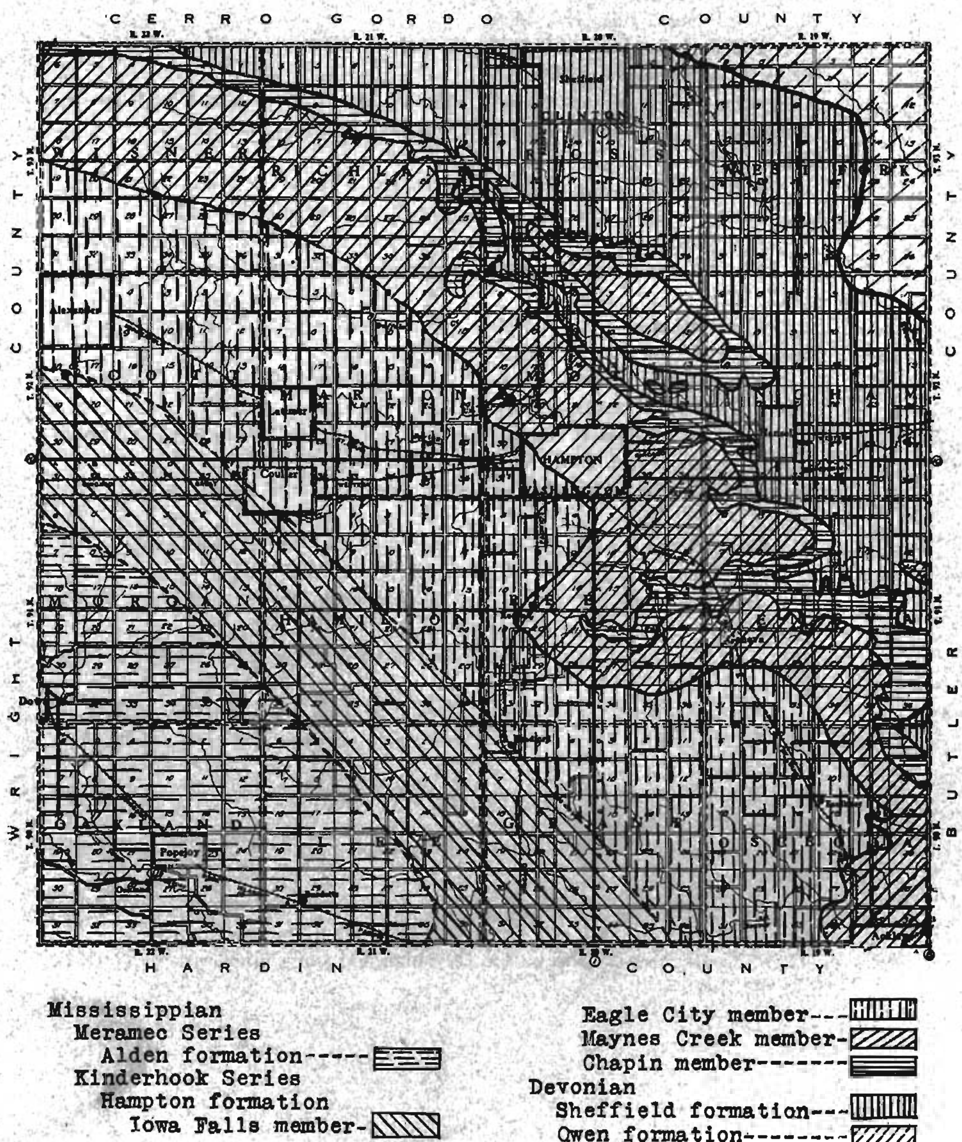


FIG. 64.—Areal geology map of Franklin county.

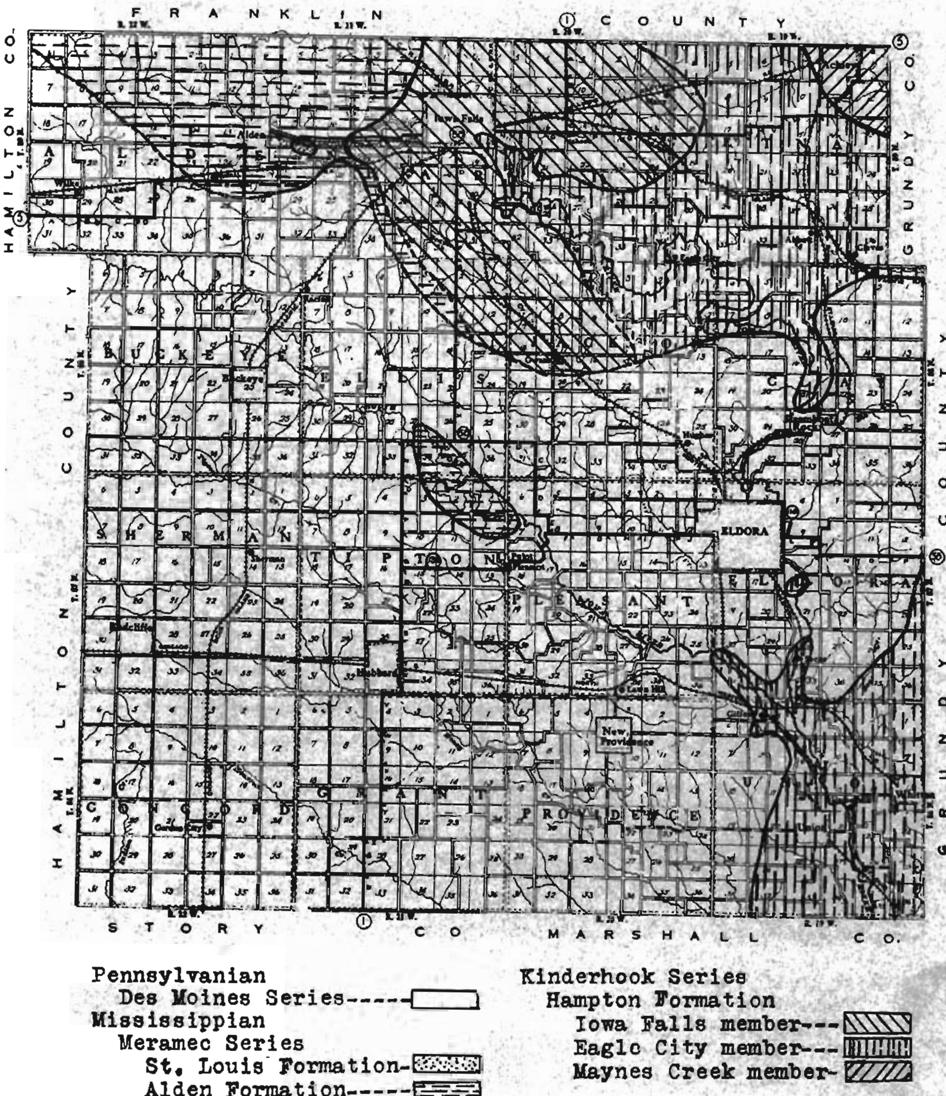


FIG. 65.—Areal geology map of Hardin county.

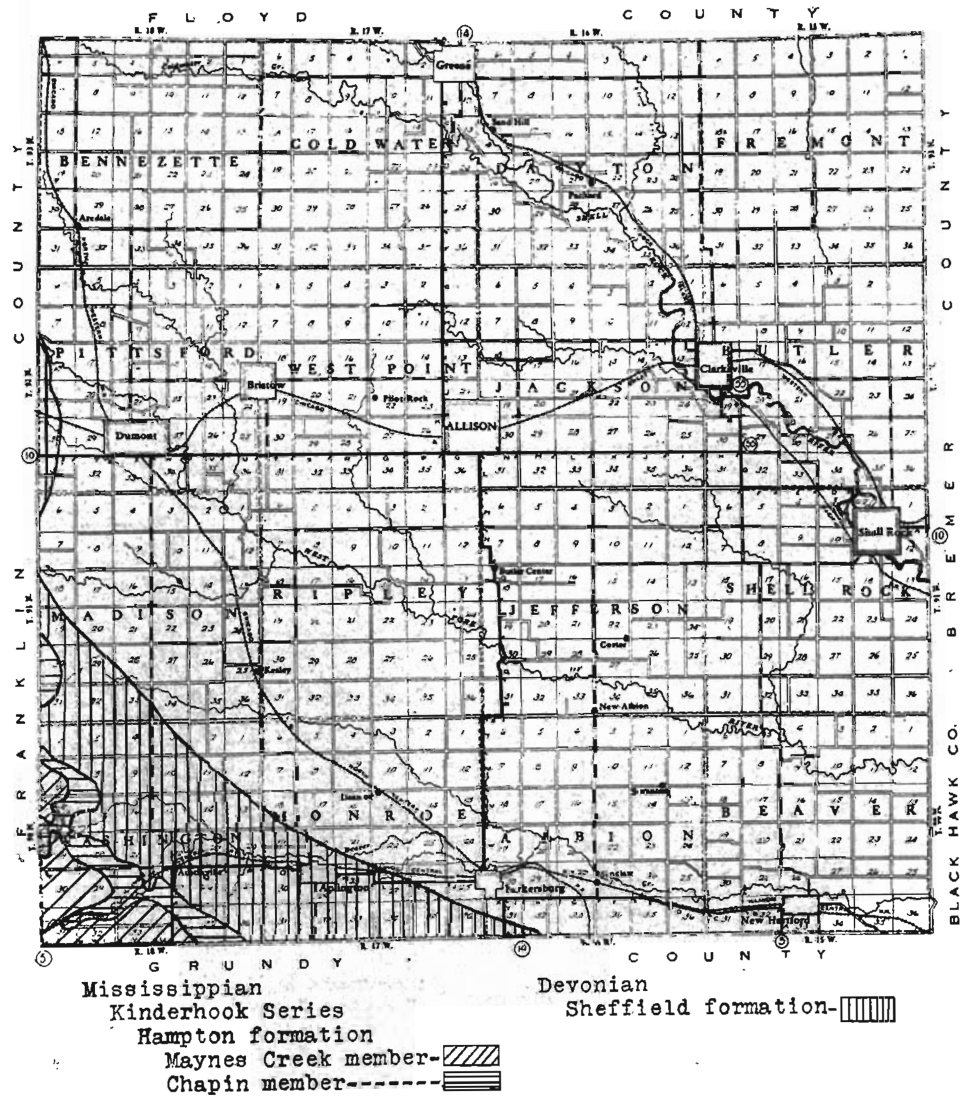
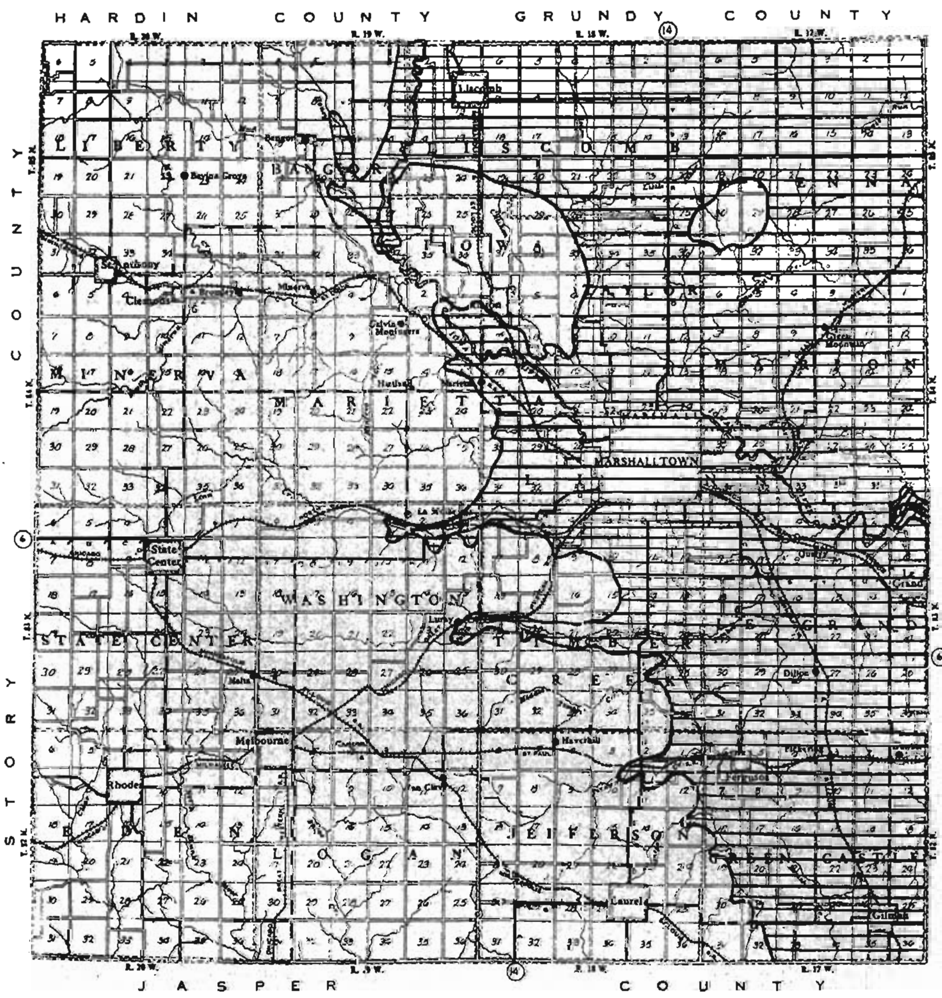
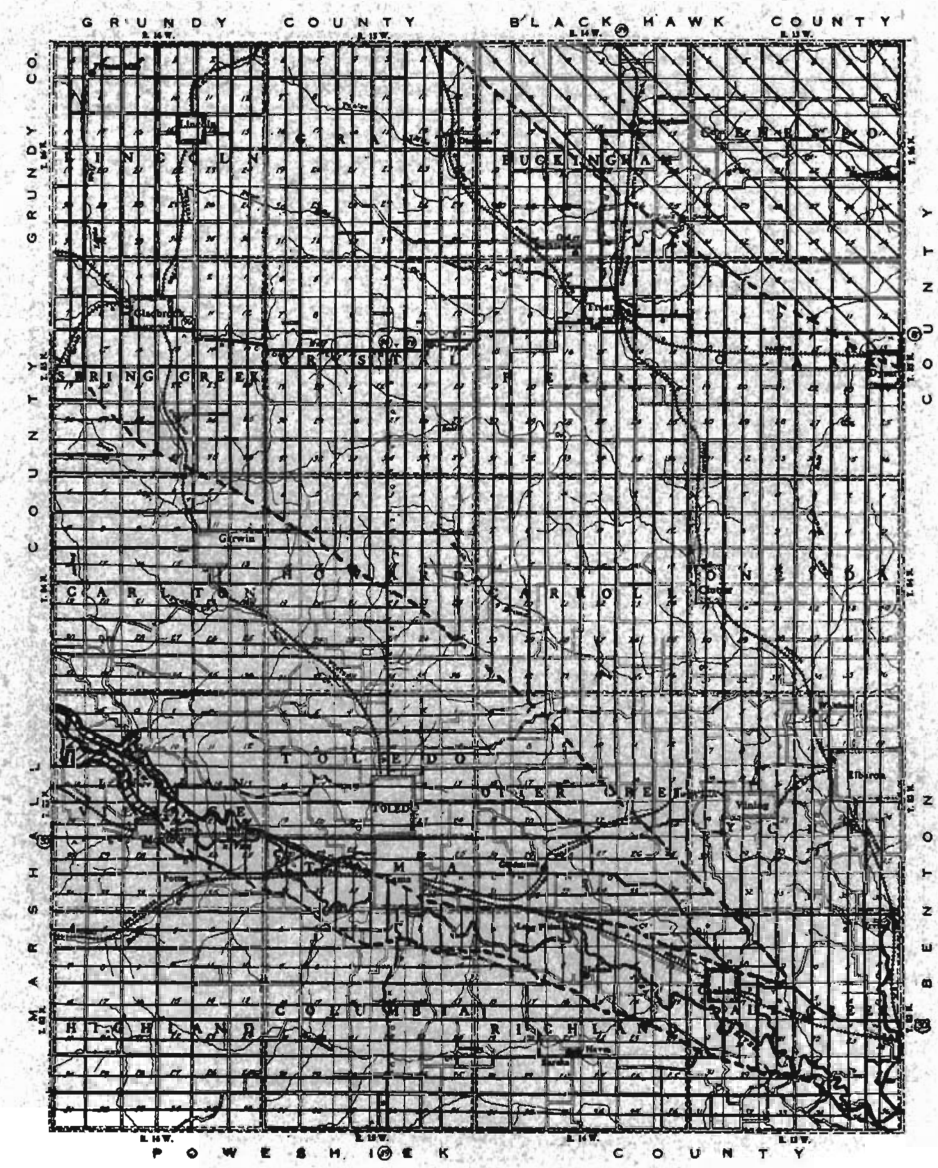


FIG. 66.—Areal geology map of Butler county.



Pennsylvanian
Des Moines Series---------
Mississippian
Kinderhook Series
Hampton formation-------
English River formation-
Devonian
Chemung Series
Sheffield formation-

FIG. 67.—Areal geology map of Marshall county.



Mississippian
Kinderhook Series
Hampton formation--------
English River formation-

Devonian
Sheffield formation----
Cedar Valley Formation-

FIG. 68.—Areal geology map of Tama county.

INDEX

D

NATURAL MOLDING SANDS OF IOWA

by

JOHN E. SMITH

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ILLUSTRATIONS

NATURAL MOLDING SANDS OF IOWA

Introduction

Natural molding sand is a mixture of sand, silt and clay in such proportions as to make it adapted for use in various kinds of foundry work. Commonly the amount of clay varies from about five to nearly thirty per cent.

The amount of material of each size for the samples analyzed is shown in the table on page 460. The figures given in the column designated "On 100", for example, indicate the percentages of the respective totals that remained on the screen having 100 meshes to the linear inch when the test was made. The same is true in each column having a similar heading.

Tests on Foundry Sand

All tests given in the table on page 460 were made in accordance with the methods set forth by the Joint Committee on Molding Sand Research (see American Foundrymen's Assn. bulletin, June 1, 1924, edition corrected Aug. 1, 1924). This work was conducted by Dr. H. Ries of Cornell University, Ithaca, New York.

Permeability.—The gases that are formed when molten metal is poured into the mold, such as steam and expanding air, must have an easy means of escape through the sand in such a way as not to disturb the position of the sand while the pouring and cooling are in progress. By means of the standard test used permeability is determined as the volume of air per minute, per gram per square centimeter pressure, per unit volume in the specimen.

Permeability is best when the various size grains of the molding sand are evenly distributed throughout the mixture. If the sand grains are too evenly covered with clay permeability may be low or poor. A small amount of very fine material obstructs the easy passage of the gases through the sand. The clay, like other textures, should be evenly distributed throughout the mass.

The best results in tests of bond strength seem to be obtained when the water content is between four and six per cent. The bonding strength is given in grams of actual weight of the average breaking strength of a bar of molding sand made under standard conditions. (See American Foundrymen's Assn. bulletin, June 1, 1924, also bulletin 50, Illinois Geol. Survey, by M. S. Littlefield.)

Description of Iowa Molding Sands

Benton County.—One exposure of good molding sand adapted for use in bench work and in other light work was found one mile east and one and three-fourths miles south of Garrison (the nearest railway station), where about ten feet of coarse-grained loess underlies some five feet of cover in a roadside cut.

North of Shellsburg, two and one-half miles, near the middle of the east half of the northeast quarter of section 34, Township 85 North, Range 9 West, in a cut on the east side of the highway, is located a deposit of molding sand about ten feet thick. Though suited to use in gray iron work, this material for the most part lies under heavy cover and has no commercial value at present. Apparently it is glacio-fluvial material formed as outwash at the margin of the ice during a recessional stage of the Iowan glaciers.

Black Hawk County.—In several places in and near Waterloo molding sand has been produced but no areas of it are being worked at present. Most, if not all, of this seems to have had an eolian origin.

Alluvial sand and "bank sand" or that found in areas of glacial outwash east of the river have yielded core sand in this vicinity. Some of this sand has been reworked by the wind.

Along the bluffs nearly a mile west of La Porte City both east and west of the old quarry a layer of good molding sand, one to three feet thick, rests on glacial till and is covered with a zone of soil two to three feet thick. This area of molding sand is probably not very extensive and is doubtless of eolian origin. It is suitable for use in bench and light floor work.

Boone County.—One location yielding a sample of what seems to be an excellent molding sand was found in Boone county. It occurs in a roadside bank where the road leaves a river terrace on the right side of the Des Moines river valley and is about 20 feet above the flood plain. This location is about three miles west of Madrid in the southwest quarter of the northwest quarter of section 27, Township 82 North, Range 26 West. It lies beneath an overburden of nearly ten feet and is, therefore, of doubtful commercial value. Only field tests were made on this sand. It is a river terrace deposit and was formed as alluvium at a time when the surface of the river water was much higher than at present.

Bremer County.—One mile north of Waverly in the southwest quarter of the southeast quarter of section 26, Township 92 North, Range 14 West, good molding sand was found in several places. Toward the northwestern or windward ends of the eolian hills in this part of the county molding sand may be found in numerous localities. Such deposits range in thickness from a few inches to four feet and are limited in extent to patches varying in size from a few square rods to half an acre. No sand from here has been used but the deposit has a possibility as a short-lived field.

Cedar County.—No molding sand is produced in this county but a good quality of material is found in several places in road cuts along Lincoln Highway west of Stanwood and west of Mechanicsville. These illustrate well the eolian type of origin and consist of alternating bands of sand and clay up to one inch thick. In a few of these outcrops good molding sand can be found in layers up to five feet thick. There is, however, little hope for commercial development because of the irregularity in thickness and extent of the deposits.

A Typical Section	FEET
1. Soil and subsoil	4
2. Clay, loess, somewhat sandy	2
3. Clay, loess, and sand, many alternating layers, less than one inch thick, mostly good molding sand	5

IDENTIFICATION OF THE SANDS IN TABLE OF TEST RESULTS

Number 1. A core sand from the Prier pit at Marshalltown. See page 469 also. 2. A molding sand from the Williams pit four miles east of Marshalltown, location and description given on page 469. 3. See page 463 for location of the place from which sample number three, a molding sand, was obtained near Floyd Station in Floyd county.

4. A molding sand from pit at Nora Springs, Floyd county, operated by the Hart-Parr Company. See page 463. 5. Molding sand from the Chinn pit on Harrison Road at Clinton. See also page 462. 6. A molding sand from the Vosburg pit at Clinton. See page 462. 7. A molding sand from Oak Hill, Cedar Rapids. See page 468. 8. See page 471 for details concerning the molding sand from the Harris pit at Des Moines.

9. A molding sand from the Ben Lufkin pit at Reasnor, Jasper county. See page 464 and figure 69. 10. Core sand from the Franklin pit at Ottumwa. See page 475 and figures 78 and 79. 11. Molding sand from Muscatine. See page 470 and figure 74. 12. Molding sand from Johnson county about four miles north of Iowa City. See page 464 and figure 70.

13. Molding sand from Dallas City, Illinois. 14. Molding sand from Milan, Illinois. 15. Molding sand, "No. 1", from Albany, New York (The analyses of numbers 13, 14 and 15 are taken from bulletin number 50, Illinois Geological Survey, by M. S. Littlefield).

Tests of Iowa Molding Sands

No.	On 20	On 40	On 70	On 100	On 140	On 200	On 270	Through 270	Clay Subs.	Total	Water per cent	Bond Str.	Perm.
1	.30	1.02	1.38	1.54	1.28	1.48	6.9	45.7	39.76	99.36	4.7 5.8 6.7 8.5 10.5 12. 13.7	326 336 290 273	1.4 4.2 4.4 4.4 7. 7.7 7.7
2		1.92	57.8	27.9	7.34	1.34	.34	.1	2.82	99.56	2. 2.4 3.5 5.7	121 100 88 85	185. 178. 167. 156.
3		.78	4.24	1.8	1.48	1.72	11.34	54.38	24.	99.74	4.7 6.6 8.2 9.7 12.6	268 257	3.1 3.5 4.4 9.4 7.7
4	.5	9.34	29.	12.88	5.34	4.68	7.24	13.34	17.02	99.34	3.2 4.4 6.3 8.3	240 298 290 275	40. 50. 49. 42.
5		.94	8.08	31.9	15.88	10.1	12.28	12.46	7.76	99.4	5.9 7.6 9.6	131 140 131	17.8 19.5 15.7
6		.24	4.78	13.38	9.84	20.3	19.2	23.14	8.26	99.14	4.5 5.3 8.	160 142 140	27. 25.8 24.2

7		.48	6.28	7.64	6.78	5.5	13.8	39.14	20.1	99.72	3.3 3.9 6. 8.1	248 229 197 178	8.2 9. 8.5 7.9
8		.26	6.	14.06	15.	13.44	18.8	18.98	12.64	99.18	4.3. 6.3 8.4 10.3	247 230	9. 13. 21.8 17.3
9		Tr.	.68	1.98	3.44	5.74	15.24	57.2	17.	99.28	5.8 8.1 9.9 12.2	150 182 186 184	7. 8.5 7. 6.5
10	.26	10.06	59.2	11.5	1.34	.8	.94	2.36	13.3	99.76	4.2 6.4 8.8	345 375 290	193. 219. 126.
11	Tr.	.74	19.74	14.64	6.64	3.04	7.64	25.6	22.06	100.1	3. 4.1 6.2 8.2	256 219 213	6. 8.2 7.7 7.
12	Tr.	2.9	31.54	16.34	6.9	3.48	2.98	12.88	22.26	99.28	3. 4.1 6.1 7.9 10. 11.5	265 262 251	12.6 19. 33. 40. 1.1
13	.4	2.	18.7	12.1	9.3	13.	5.	29.1	9.4	99.	4. 6. 8.	181.5 197.8 173.8	13.2 13. 12.6
14		1.2	9.8	7.1	7.4	11.8	19.8	33.8	8.2	99.1	4. 6. 8.	236.4 271.4 261.8	4.4 4.6 4.7
15		.2	1.3	2.9	9.5	29.	15.9	34.4	5.9	99.1	4. 6. 8.	140.3 144.2 146.0	15.5 13.7 14.2

Clayton County.—A high grade silica sand is quarried from an outcrop of St. Peter sandstone at Clayton. This is a clean white sand testing 98 per cent to 99 per cent SiO_2. It is the geological equivalent of the well-known silica sand produced at Ottawa, Illinois. It is used in cast steel molding at Waterloo.

Clinton County.—The pit from which sample number 5 was taken is located on Harrison Road about two blocks from Lincoln Highway and three to four blocks from rail spur at the plant of the Collis Manufacturing Company. The pit is owned by F. A. Chinn, and is a part of several acres in the southwest quarter of the southwest quarter of section 14, Township 81 North, Range 6 East.

Section in the Chinn Pit	Feet
1. Soil and subsoil, a light brown sand	1–3
2. Sand, molding. Shows dune structure in alternation of layers from one to five inches thick and containing less clay than other strata which have a similar thickness, which makes them stand out in relief as the face weathers.	

Sample number 6 was taken from the P. E. Vosburg pit located near the crest of the hill on Tenth Street.

Section of the Vosburg Pit	Feet
1. Soil	3
2. Sand, molding	2
3. Sand, core, exposed	4

Along the slope of the hill on the south side of Harrison Road there are many small areas in which good molding sand pits could be opened. A test was made in a bank on Fourteenth Street one block from Harrison Road and an excellent quality of molding sand was found.

Dallas County.—About three miles east of Redfield in the northeast corner of section 2, Township 78 North, Range 29 West, the highway cuts through an area of sandy deposits near the margin of the Wisconsin glacial drift. The field tests indicate that some of this material is good molding sand and since it is located within half a mile of the Chicago, Milwaukee, St. Paul and Pacific railroad it may some time have a shipping value. An exposure of approximately 15 feet exists here under five to six feet of glacial till.

Des Moines County.—A few areas containing molding sand were found on the low river terraces in the region south of Burlington. Some of these areas are along the highway near the Burlington track in the east half of section 35, (Union) Township 69 North, Range 3

West. This is partly a coarse, heavy, red sand suitable for use in medium to heavy castings but several grades for use in lighter work also are found here.

Dubuque County.—No molding sand is produced in Dubuque county. Most of the sand used here is brought from the bluffs just across the river. On the Iowa side some loess is found but most of it is too fine for any use as molding sand.

Floyd County.—Sample number 3 was taken from the roadside pit on the farm of F. O. Martin, 300 yards from the railroad station in the southeast quarter of the southeast quarter of section 9, Township 96 North, Range 16 West. This is an eolian ridge extending for some distance in an east-west direction on both sides of the road. The sample was taken from numbers three and four of the section below. It is reported that some sand has been shipped from this pit.

	Section	FEET
1.	Soil and subsoil	3
2.	Clay, tight and dry, "hard pan"	1½
3.	Clay, loess, leached, good molding sand	2
4.	Clay, loess, calcareous, to level of highway	4

Sample number 4 was collected in the northwest quarter of the northeast quarter of section 18, Township 96 North, Range 18 West. This property is in charge of the Hart-Parr Company and the sand is used in their plant at Charles City. Sample was taken from numbers 2, 3 and 4 of the section.

	Section	FEET
1.	Soil and subsoil, brown, oxidized and leached	2
2.	Clay, arenaceous, good molding sand, leached	1
3.	Clay, arenaceous, first class molding sand, leached	1
4.	Sand, containing three two-inch streaks, with much clay, leached; to bottom of pit	1

Several other areas in the county contain molding sand. Probably those having the largest extent are in Scott township several miles west of Marble Rock.

Iowa County.—Several areas along the south side of the Iowa river valley in this county contain good molding sand but no exploiting has been done. A typical location and section is found in the highway cuts between the northern parts of sections 3 and 4, Township 80 North, Range 10 West.

Section		Feet
1.	Soil and subsoil	3–4
2.	Clay, arenaceous, loess, good molding sand, suitable for use in casting aluminum, brass and other light work	10

Jasper County.—In Jasper county the principal producing locality is near the city of Reasnor on the property of Mr. Ben Lufkin. The pit is in the southwest quarter of the northeast quarter of section 11, Township 78 North, Range 19 West. It is cut in an eolian ridge extending in a northwest-southeast direction, a section of which is as follows:

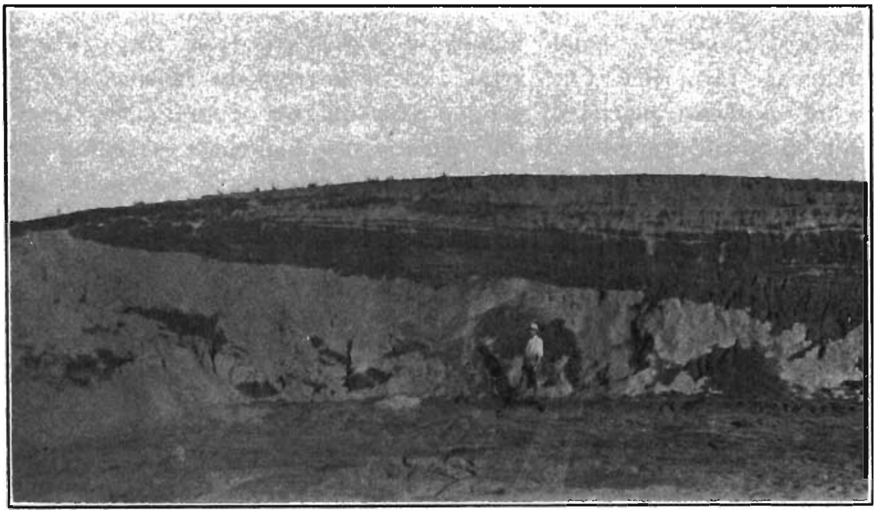

Fig. 69.—A view taken in the pit owned by Mr. Ben Lufkin at Reasnor, Jasper county. See below for description of the layers of molding sand from which sample number nine was obtained.

Section		Feet
1.	Soil and subsoil	2
2.	Molding sand, suitable for light bench work, used in molding aluminum work at Newton, Davenport, etc.	6– 8
3.	Sand used in asphalt paving work	10–12
4.	Glacial till	

This locality lies within a mile from the railway station, and its elevation is high enough so that the haul is down grade most of the way.

Johnson County.—Sample number 12 was collected from a roadside cut on the Red Ball highway in the northwest quarter of the southwest quarter of section 21, (Penn) Township 80 North, Range 6 West. The material was taken from number 2 of the section given below.

Section	FEET
1. Soil and subsoil	2-3
2. Sand, argillaceous, reddish brown, a molding sand with good bond, adapted to gray iron castings	4-5
3. Clay, sandy, with a few irregular layers of molding sand 4 to 6 inches thick, exposed	3-4

This is eolian in origin and is located about half a mile from the margin of the Johnson county lobe of the Iowan ice as shown on the maps. (See fig. 70 and table, p. 460.)

FIG. 70.—Sample number 12 was obtained from the uphill roadside bank near the middle of this picture. Johnson county, see page 464.

A good exposure is found in a road cut west of Tiffin in the southwest quarter of the northwest quarter of section 29 near the cemetery. The eolian character of the deposit is seen in figure 71.

Section West of Tiffin	FEET
1. Clay and soil	4-6
2. Clay, sandy, molding sand for light to medium work (lens shape)	0-10

One of the thickest deposits of molding sand in the state and one well located for shipping (50 yards from track, one-fourth mile from station) is found on the Jos. Ray estate at Midriver in the southeast quarter of the southeast quarter of section 27, Township 81 North, Range 7 West.

Section at Midriver	FEET
1. Soil and subsoil	3-4
2. Sand, clayey, good fine-textured molding sand	3

3.	Sand, fine	1
4.	Sand, clayey, noncalcareous, buff to yellow, suitable to use in gray iron and brass work; to level of highway	25

Several other deposits of minor importance were found in the county.

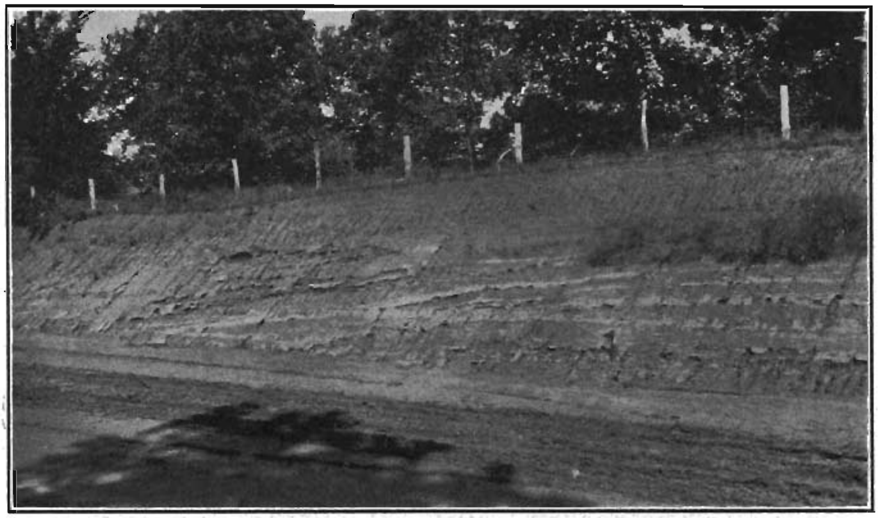

FIG. 71.—The material seen in this cut was blown by the wind from the left, northwest. The hill has been built up by successive additions, several of which can be seen overlapping those below. Rows of concretions are seen near the right margin. This cut is in Johnson county, west of Tiffin, as described on page 465.

Lee County.—One locality having a grade of molding sand in quantity and quality indicating some degree of commercial promise is found in a ridge crossing the east-west highway in the middle of the eastern half of section 15, Township 67 North, Range 5 West. This is a deposit of river terrace sand worked over and developed as a ridge by the wind. This is within five miles of Fort Madison and less than a mile from the Santa Fe railway. It is a grade of sand adapted to use in gray iron work.

Linn County.—Two deposits of coarse red sand used as core sand and as molding sand for heavy castings were found in Linn county. One near Covington is on the east and south sides of the highways at the crossroads about one mile south of the Milwaukee railway station, in the east half of section 15, Township 83 North, Range 8 West, on the farm of F. M. Davis.

	Section	FEET
1.	Soil and subsoil	2–3
2.	Clay, sandy, loess	1–2
3.	Sand, clayey, a molding sand with good bond, adapted for use in me-	

	dium weight to heavy castings	2–3
4.	Sand, exposed in road cut	2

The other location of coarse red sand is found in the southwest quarter of the southwest quarter of section 19, Township 83 North, Range 7 West, just east of Edgewood school No. 1 and also across the

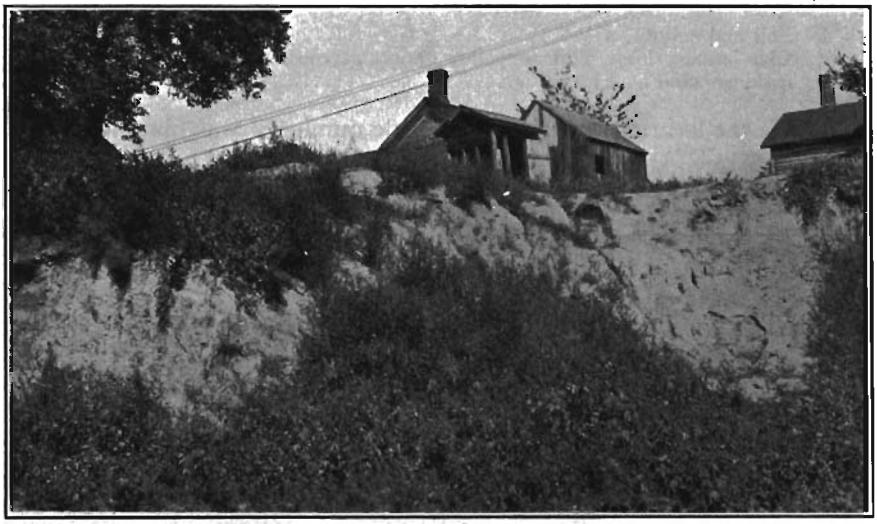

FIG. 72.—The molding sand of sample number seven was taken from this pit on Oak Hill in Cedar Rapids. The molding sand is at left of the weeds and the lower left corner of the cut shows weathered Kansan till. See description on page 468, and analyses on page 460.

road westward and northwestward from the school property. It is in a ridge that extends nearly northwest and southeast, and on which the Edgewood school is located. The section is very similar to that given for the exposure near Covington. See location on special map p. 468.

Other typical sections on the west side of Cedar river in Linn county include molding sands having a finer texture than those given above and suited to use in gray iron, brass and aluminum work. One section which may be taken as a type is found in the southeast quarter of the southwest quarter of section 24, Township 83 North, Range 8 West, in the Red Ball road cut on the farm of L. Beemer.

	Section on L. Beemer's Farm	FEET
1.	Soil and subsoil	2–3
2.	Clay, loess, hard	2–3
3.	Sand, rather fine-grained, loess, the grade used in brass, aluminum and light gray iron work, yellow to brown, noncalcareous throughout	10–12
4.	Sand, coarser	3

This deposit, like a similar one across the road south of it on the Weaver estate, is several acres in extent. Several sections very much like the one on the Beemer farm are found southward on the west side of the river within five miles of the city, and several others within the city limits.

Section at Oak Hill		FEET
1.	Soil and subsoil	2
2.	Clay, sandy, loess, buff to yellow, noncalcareous, a good grade of molding sand	10

This is the location from which sample number 7 was obtained. The property is owned and the sand has been used by the Iowa Steel and

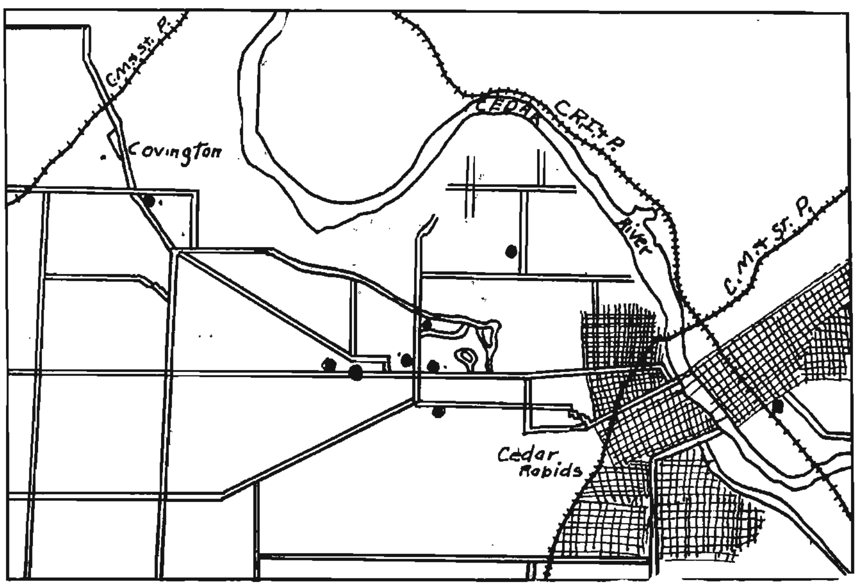

FIG. 73.—The black square shows the location of the Oak Hill pit. Black circles indicate foundry sand of probable commercial value. A dot beside a black circle indicates red core sand.

Iron Works. It is an eolian deposit on the leeward side of a small knob of Kansan glacial till, the top of which is seen in the alley at the rear of the property. Sand from this pit was first used by the Dearborn Brass Works of Cedar Rapids to displace sand shipped from Albany, N. Y.

Louisa County.—A typical deposit is found about two miles east of Fredonia, just east of the middle of section 22, Concord township, in a road cut on the "Great White Way". On the south side of the road, the property is owned by E. S. Curtis and on the north side by Mrs. Mary D. Newell, both of Columbus Junction.

	Section	FEET
1.	Soil and subsoil	3–5
2.	Sand, molding, loessial material, chiefly of the type used in bench work	10–16

There are doubtless other areas along the east side of this ancient lake that contain molding sand, most of which lies hidden at a depth of several feet. This material has the appearance of having been blown from the west or northwest to its present hillside and hilltop positions.

Marshall County.—Sample number 2 was taken from the pit owned by Lester Williams and located about four miles east of Marshalltown in the northeast quarter of the southwest quarter of section 28, (Marion) Township 84 North, Range 17 West. This pit is located about one-fourth of a mile from the Chicago Great Western railroad. The pit is near the top of a hill and the highway leads directly to the railway crossing near the foot of the hill.

	Section	FEET
1.	Soil in field of clover	1
2.	Loess, molding sand, buff, with "Kindchen", calcareous throughout, texture fine to medium	8–10

Pit on the Corey Moore Farm

This pit is on the east bluff of Timber creek on the farm of Corey B. Moore near Rockland quarry in the southwest quarter of the northeast quarter of section 17, (Le Grand) Township 83 North, Range 17 West. This pit is worked by J. O. Winebrenner of Marshalltown. The product is a fine to medium-grained molding sand and is used by foundries in Marshalltown.

Core sand is produced for local use at the pit of the Walter H. Prier Company near their plant two blocks north of the Fair Grounds in Marshalltown.

	Section in the Prier Pit	FEET
1.	Soil and subsoil	2–4
2.	Sand, with several 1 to 2 inch seams of brownish clay	2–3
3.	Sand, finer in texture and cleaner, exposed	3

Sample number 1 was taken from numbers 2 and 3 in this pit. The position, extent and structure within the pit indicate that it is a dune ridge whose sand probably had its origin in a flood-plain deposit.

Montgomery County.—An exposure of material said by experienced foundrymen to be an excellent molding sand occurs in the bluff beside the railroad about a mile southwest of Red Oak on the farm of Anton Neuman in the southeast quarter of the northwest quarter of section 32, Township 71 North, Range 38 West.

The section here shows about ten feet of sandstone very poorly consolidated and having in its upper part several layers or bands of limonite from one-half inch to two inches thick. Above this in the section is two and one-half to three feet of conglomerate which in turn is covered by several feet of glacial till in the slope of the hill. The molding sand lies below the limonite layers, which are several inches apart. The overburden is so thick that this material has not been used for several years. If the overburden or part of it could be used for road material, it and the molding sand might again become an economic possibility.

Muscatine County (See map p. 474).—A pit which has been producing for ten years or more is located opposite the Heinz Manufacturing Company's plant in a northern suburb of Muscatine within 100 yards of the electric railway. This property was in charge of E. O. Burnside in 1925.

Section of Pit	FEET
1. Clay, loess	5–6
2. Molding sand, contains alternating seams of coarser and finer textures but makes a good average	5–8
3. Clay, glacial till, exposed	2–3

The extent of this deposit is unknown but it seems to include several acres. Probably it decreases in thickness, giving way to loess toward the top of the hill.

Good molding sand is found also in several narrow eolian ridges which cross the "Great White Way" north of the middle of section 34, Township 76 North, Range 3 West. Most of this is in the northwest quarter of the section and lies on the upland about eight miles west of Muscatine. These ridges vary from 100 yards to a quarter of a mile in length and contain molding sand one to three feet thick under two to three feet of soil.

Good core sand of eolian origin but probably not of commercial importance was found in the southwest quarter of the southwest quarter of section 29, Township 78 North, Range 1 East, and in a roadside cut near the middle of the north line of the northeast quarter of section 2. Township 77 North, Range 1 West. Good red core sand is found about one and one-half miles east of Muscatine in a bank on the side of the River road in the northeast quarter of the southwest quarter of section 30, Township 77 North, Range 1 West, and also on the west side of section 28 where the same road enters the section about three miles east of Muscatine.

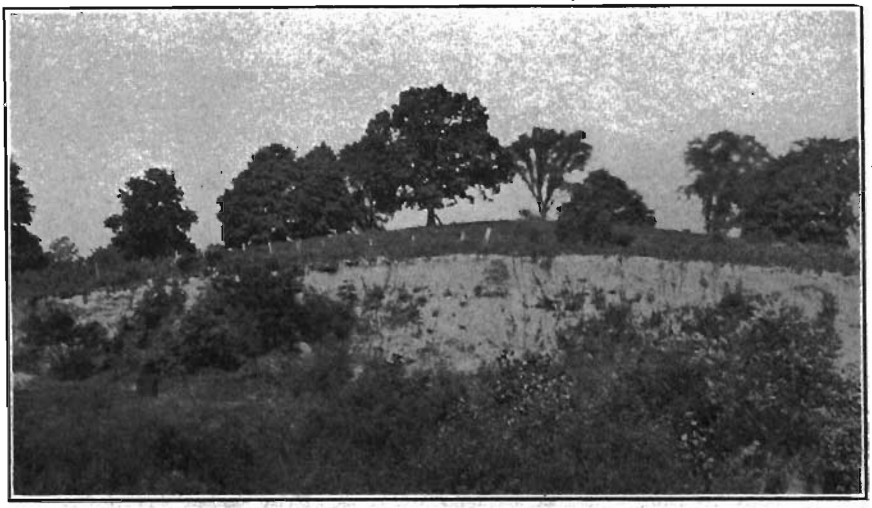

FIG. 74.—A view in the pit at Muscatine from which sample number 11 was taken. See page 470.

A good sand used in the blast for cleaning castings is produced by screening alluvial sand at the plant of the Northern Gravel Company.

Polk County.—The only producing pit in Polk county is the Leon Harris pit in Saylor township, in the northwest quarter of the northeast quarter of section 22, Township 79 North, Range 24 West. This property lies along the Interurban tracks north of Highland Park near the paved road. It is also near the Saylor Center school. Several grades of sand may be obtained from this pit, ranging from fine to coarse-textured material.

Section	FEET
1. Soil and subsoil	3–4
2. Sand, molding, with 2-inch layers of coarser sand	3–4

Sample number 8 was taken from number 2 of this section. The deposit apparently extends for some distance to the west and to the north. See figure 75.

Other Deposits of Molding Sand

Several deposits of good molding sand were exposed at the time this survey was made along banks and vacant lots on north Sixth Avenue and one at Shawnee Avenue. These will decrease in availability as this suburb develops. A layer of rather coarse molding sand about one foot thick was found on the property of the Flint Brick Company near the top of the bluff. Most of this is in the east half of the southeast quarter of section 24 of Saylor township.

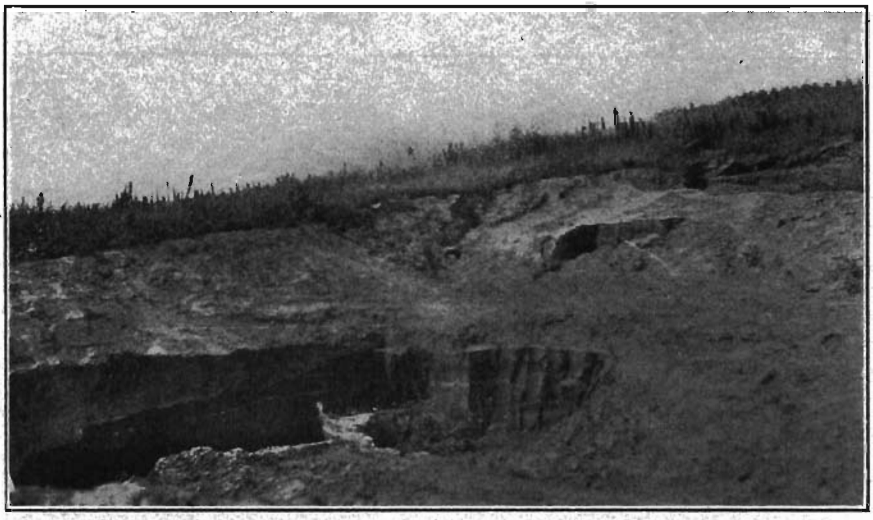

FIG. 75.—A view in the Harris pit at Des Moines showing three openings, each of which produces a molding sand slightly different from the others. Sample number eight was obtained from the large pit in the foreground. See page 460.

These deposits seem to be eolian in character and in topographic position. They lie along the slope and near the top of a rise which is southeast of the broad, flat flood plain of Des Moines river where the present valley crosses the ancient valley of its predecessor. This alluvial plain probably is the source of the wind-blown sand.

Scott County.—One-fourth of a mile south of Dixon in the road cut is an exposure of good molding sand 10 to 12 feet thick under a cover of soil and subsoil three to five feet thick. This occurs in the form of a narrow ridge of loess half a mile long extending nearly northwest and southeast. Thousands of tons of molding sand are available here at a distance of less than half a mile from the railroads (C., M., St. P. & P., and the C., R. I. & P.). It is yellow to brown in color and is of the type of sand used in aluminum and light gray iron work. It is eolian in origin.

FIG. 76.—The first twelve feet upward from the bottom of the road cut shown here is good molding sand. This is located near Dixon, Scott county, as shown on the map on page 474.

At Donahue two good exposures of molding sand were found about a mile north of the railway station: one a few yards east of the cross-roads and one about 300 yards north of the intersection. The sands here are coarser than at other places described for this county.

A bank of loess at the roadside one and three-fourths miles east of Long Grove stands 25 feet high under cover of five feet of soil and subsoil. It has the right texture for molding sand for light bench work and is located within half a mile of the paved highway between DeWitt and Davenport. An abundance of this sand is in evidence.

A few other places in the county could produce molding sand but have no commercial value for this purpose at present. See map, fig. 77.

Tama County.—Molding sand of good grade and thickness is found on the south and east sides of the highway intersection east of Montour in the northwest quarter of the southwest quarter of section 26, Township 83 North, Range 16 West, on Lincoln Highway. Here as in several other places more than one grade of sand can be obtained.

	Section East of Montour	FEET
1.	Soil and subsoil	6
2.	Clay with sand, molding sand for light floor work	3
3.	Clay with fine sand, for use in brass and aluminum castings	5

Several exposures of good molding sand are found in the road cuts along Lincoln Highway on the north side of the Iowa river valley in the eastern part of the county with Chelsea as the nearest central point. A corresponding series of deposits occurs also on the south side and on

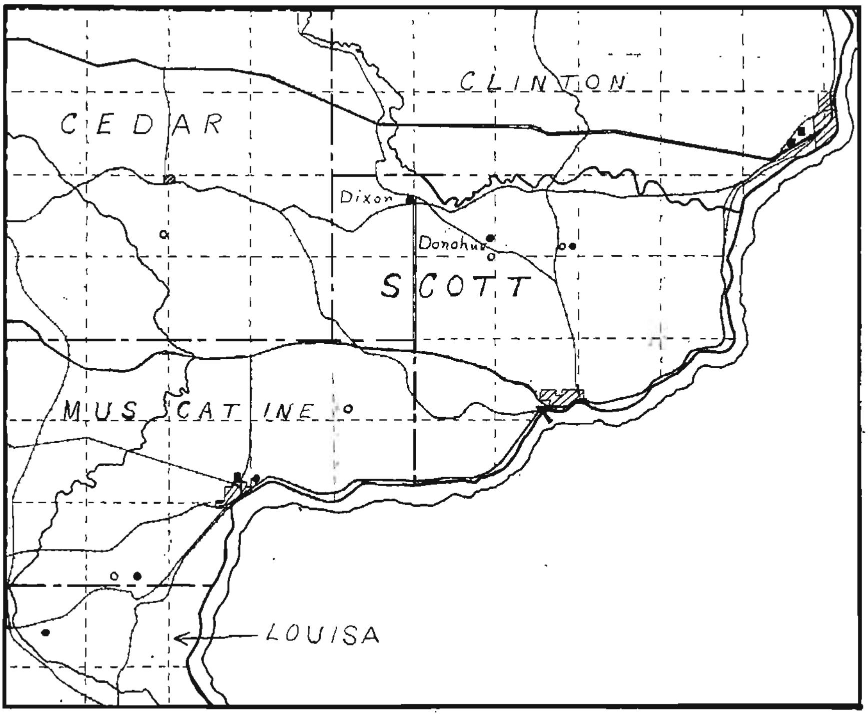

FIG. 77.—Pits producing molding sand are shown in shaded squares. Areas believed to be possible commercial producers are shown in black circles. The black circle just east of Muscatine indicates location of red core sand. Open circles indicate unimportant localities.

the south bluff of the valley chiefly in (Richland) Township 82 North, Range 14 West. None of these deposits has been exploited.

About two miles east of Tama on Lincoln Highway in the road cut at the Summit farm, the following section was seen.

Section East of Tama	FEET
1. Soil and subsoil	4–7
2. Clay mixed with sand, a good molding sand for light work	6–10

At several other places both east and west of Tama openings could be developed as producing pits of molding sand.

Wapello County.—The foundry sand production of Wapello consists chiefly of material that is used as core sand. This may be classed as river sand, "bank sand" and bluff sand. The first of these is alluvial; the second, chiefly eolian; the third is probably eolian and residual.

Eddyville.—The "yellow bank sand" half a mile east of Eddyville is obtained from a pit in an area decidedly eolian in character. This area is located at the top and on the upper slope of the valley wall along the eastern boundary of the northeast quarter of section 6, Township 73 North, Range 15 West.

On the farm of the owner of this property, Mr. S. L. Lemmon, a ridge has been formed by drifting sand along an old fence row and in this ridge, Mr. Lemmon reports, two fences have been buried deeply enough to require that new fences be built.

Ottumwa.—Sample number 10 was taken from the Henry J. Franklin pit, see figure 78, at the upper end of Randolph Street and near the middle of the boundary line between sections 13 and 14, Township 72 North, Range 14 West.

	Section in the Franklin Pit	FEET
1.	Soil and subsoil	2
2.	Clay, loess, mottled brown	3
3.	Clay, loess, mottled gray and brown	4
4.	Clay, loess, dark color	3
5.	Sand, mixed with clay, red, core sand, also used as molding sand for extra heavy castings	6–10
6.	Sand, red, finer in texture than number five above; to bottom of pit	3–5

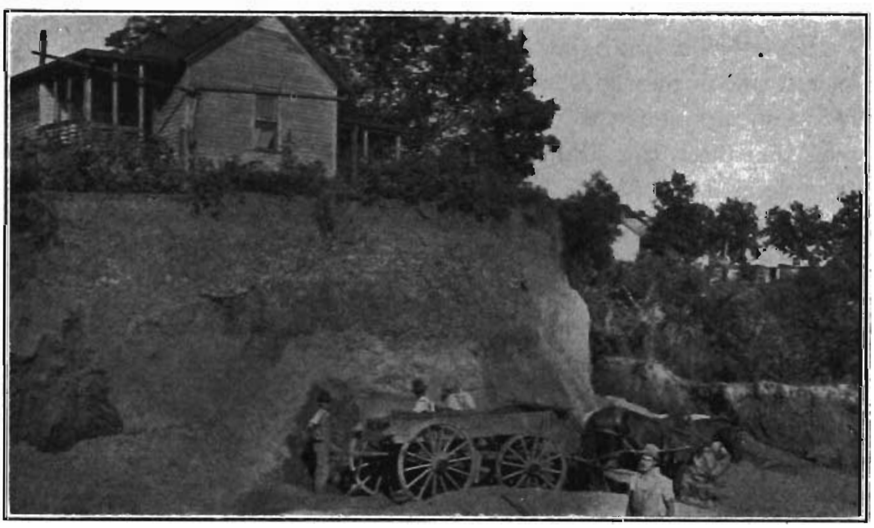

FIG. 78.—A view in the Franklin pit at Ottumwa where sample number 10 was obtained. This shows the methods employed in exploitation. See page 460.

Sand is taken from numbers 5 and 6 of this section and loaded into box cars about one mile from the pit, see figures 78 and 79.

FIG. 79.—The method of loading cars at Ottumwa with molding sand from the Franklin pit, Ottumwa, is shown here.

Similar sand is found in a pit opened at the foot of the hill, half a mile south of the Franklin pit, along the creek opposite the base ball park, and also on both sides of South Walnut Street near South Main Street.

Origin.—The position of this material above the Kansan till and on east side of the valley suggests that it is eolian sand covered by loess. It is noncalcareous throughout and this with its deep red color indicates that the entire section given above has been subjected to intense or prolonged weathering. It is therefore believed to be a natural mixture of glacial, eolian and residual material.

This sand is used extensively by the Holland Furnace Company at Cedar Rapids.

Geology

Foundry sand or molding sand as it is more commonly called is a mixture of several sizes of sand with clay and water. The proportions of each size of sand differ considerably as may be seen from the table of analyses given on page 460. The clay commonly ranges from five per cent to thirty per cent and the water from three to eight per cent, with a few extremes exceeding these limits. It must be coarse enough to permit the gases from the molten metal as it cools to pass through between the grains easily and yet without causing movement among them. For use in making small screws, small lock keys, and other small objects of brass and aluminum, a very fine sand is necessary and loess is commonly employed for this purpose, also for some of the larger and heavier work, but for much of the latter a coarser sand must be provided. Natural mixtures of these substances are commonly used except for special kinds of work and for steel casting. For these artificial mixtures are prepared.

Few of the deposits of molding sand studied seem to be the result of a single geological process. Most of them are found to have originated from the work of several agencies, one of which, the wind, is chiefly dominant. Some of the terrace deposits, that west of Madrid in Boone county for example, are strictly alluvial, having been formed as flood-plain deposits at a time when the river valley was not so deep as at present and then covered to a depth of several feet before a part of the valley bottom was cut down to its present level.

On wide flood plains the wind seems to have moved much of the finer material and some of the coarser, depositing it in ridges or other forms of drift on the flood plain. Most of these dune ridges extend in a direction approximately northwest and southeast. Good examples of this type are found at Marshalltown and on the Mississippi terraces southwest of Fort Madison.

Some of the alluvial deposits of the flood plains have been swept by high winds during the dry seasons to the borders of the valleys and even to the slopes and bluffs beyond, forming deposits of sand and loess. These deposits are almost invariably east and southeast of the source of the material in them, which position indicates northwest to west winds during the time of deposition of each. Deposits of this type located on the top of the bluffs are well illustrated in Marshall and Jasper counties. Pits located on the slope are found on the east side of the river at Cedar Rapids, in the city of Clinton, in the Highland Park section of Des Moines and in the northern suburbs of Ottumwa.

Some of the larger river valleys, such as the Iowa in Muscatine and Louisa counties and perhaps others, may have served as lake basins during the time that glacial ice formed dams across them. If so, the deposits blown from the bottoms of such river valleys are partly lacustrine in their origin.

Glacio-fluvial.—When glacial ice is melting the resulting water brings to its margin large quantities of clay, rock flour, fine sand, coarser sand and gravel. These materials are sorted by the water and in some places the sands and clays are mixed in the right proportions to serve as molding sands. It is obvious that such mixtures will be small and irregular in extent. The best examples of this type seen are in Dallas county east of Redfield and in Benton county north of Shellsburg.

Glacio-eolian.—On the uplands along the margins of the Iowan and Illinoian glacial deposits there are mounds, ridges and dunes of mixtures of sand and clay in various proportions. These materials, like most of the molding sands, are found southeastward from their sources. While the molding sand in these deposits is somewhat irregular in thickness and extent, it is also found to be among those sands that rank highest in quality.

Materials of this origin are derived from marginal glacial deposits by eolian extraction, transportation and deposition. Examples of this type are found in Fayette, Bremer, Johnson and Muscatine counties.

Eolian and residual.—In nearly all deposits that yield foundry sand weathering has played an important part as to origin, especially near the surface. It is only in the older Pleistocene deposits that weathering can reach its maximum influence working alone. When a large area of much weathered material is subjected to transportation by the wind it may be formed into hills and ridges composed of weathered material throughout.

Given sufficient time a deposit may weather and leach deeply. In a favorable position, as near the brink of a valley bluff in a region of higher and lower precipitation and water table, weathering takes place more rapidly than elsewhere in the vicinity and considerable depths of oxidation may be reached much more quickly than in the other topographic positions. The deposits at Ottumwa are intensely weathered but it is not entirely clear how this intense and deep oxidation was accomplished.

Reasons for "Importations"

Lack of Knowledge.—Iowa molding sands are little known. Few who own land of potential production can recognize molding sand when they see it and most of them do not even know that they have such a thing on their property. Many of these owners when this identification of material is made for them are doubtful about its commercial value or are financially unable to undertake its development or are afraid to do so. Though foundrymen want to buy sand from someone who makes a business of selling it, some of them have been forced to buy a pit or to lease one and operate it in order to obtain a reliable grade of material. The exploitation of molding sand, like that of any other kind of material, should be conducted by responsible people.

The business of marketing molding sand in many places is conducted by teamsters or truckmen who engage in it for the purpose of obtaining employment by hauling. They do not know molding sand either and some of them are very careless in loading it. They will put into the load clay or other material that is easy to obtain and thereby reduce the quality of the sand or possibly destroy its value entirely.

The sand occurs in zones or layers below the soil and subsoil, which is commonly two to three feet thick. Beneath this soil the zone of molding sand may be only one or two feet thick but in most localities a thickness of five to ten feet may be found. In several places a thickness of 15 to 20 feet exists.

It is therefore necessary for those who work in the sand pits to know thoroughly the material they are putting on the market and to use great care in doing so. In several counties in Iowa pits that would yield good molding sand have lost customers through carelessness in loading when filling orders.

Lack of Experiment.—Because of lack of experiment a full knowledge of the practical uses and adaptations of Iowa foundry sands is not available for distribution to those who may be able to save money by using Iowa's natural product. Some experimental work might be profitably carried on by the various foundries of the state and some by engineering experiment stations.

Lack of Desire.—Some of the men who are employed as molders in Iowa foundries were formerly engaged in the same work in eastern states and insist that they be provided with the same sand that they used there. This insistence brings much eastern sand into Iowa every year. That Iowa sand is equal in value or superior to the eastern sand is shown by the experience of the Dearborn Brass Works at Cedar Rapids where sand from a well-known locality of New York (Albany) was replaced by Iowa sand more than five years ago at the request of the superintendent in charge and has been used exclusively ever since.

Prepared Sand

Nearly all of the larger foundries and most of the smaller ones use in molding some sand that has been mixed in somewhat definite proportions. In steel casting a clean sand and a pure clay are used.

Most of the core sand used in gray iron work is artificially mixed with clay after being carefully screened. Of the mixed sand used in Iowa, however, the greater part is made by combining portions of natural molding sand from two or more localities. It is a common conception that any sand whose cost is high is a good one and that it will improve the quality of any sand with which it may be mixed.

Partly for this reason sand from Albany (New York) enjoys a large sale in Iowa. This is also true of some of the sand shipped here from Illinois and Ohio.

Some firms are now offering for sale molding sand prepared for use in each of the respective classes of foundry work. Such sand is finding increasing sale in Iowa, especially among the larger foundries, whose work is chiefly that of filling orders obtained by contract in which the manufacturer is to meet specifications requiring carefully standardized work.

Summary and Conclusions

Molding sand is found on and near the bluffs east and southeast of the larger stream valleys or of large curves in these valleys. It is found also on the upland in interstream areas in Benton, Cedar and a few other counties. It occurs chiefly in deposits believed to be eolian and some of these are in the form of ancient dunes now covered with soil. Part of the molding sand in some of these old dunes is a residual mixture.

In many places the deposits consist of thin layers of argillaceous sand alternating with thin layers of silt or clay in such quantities as to give the right proportions of these ingredients for molding sand. The grains of sand are coated with iron oxide which gives them a color varying from red to buff. In many places this coloring of the sand grains is somewhat uniform through a depth of five to twenty-five feet in the deposit. These deposits are believed to have been accumulated by action of the wind. When wind velocity was high the layers of coarser material were transported and this gave way to deposits of silts and clays when the wind velocity was low. Much of the coloring was done probably before the material was transported to its present position. Some of the smaller deposits of molding sand may be partly fluvial in origin.

There is an abundance of nearly all kinds of molding sand in Iowa and some of each is now being used in the various foundries of the state. The principal producing counties are Polk, Jasper, Marshall, Cedar, Floyd, Johnson, Muscatine and Wapello. Our own sand should be used much more extensively instead of that shipped here from other states.

Consumers of Molding Sand

Boone.—Boone Foundry and Machine Works; Quinn Wire and Iron Works

Burlington.—Murray Iron Works

Cedar Rapids.—Cedar Rapids Foundry and Machine Co.; Chandler Pump Co.; Dearborn Brass Works; Foster Brass Works; Holland Furnace Co.; Starry Foundry Co.; Universal Foundry Co.; Iowa Steel and Iron Works

Charles City.—Hart-Parr Company

Clarinda.—Lisle Manufacturing Company

Clinton.—Climax Engineering Co.; Clinton Lock Co., Lyons; Iowa Machine Works

Council Bluffs.—Griffin Wheel Co.; Kimball Bros. Co.

Davenport.—American Sash Weight Foundry; Black Hawk Foundry Co.; Davenport Locomotive Works, Davenport Machinery and Foundry Co.; Frank Foundry and Machine Co.; French and Hecht Manufacturing Co.; The Red Jacket Company

Des Moines.—Des Moines Foundry and Machine Co.; Eagle Iron Works; Green Furnace Company; Keith Furnace Company; New Monarch Foundry; Wood Bros. Thresher Company

Dubuque.—The Adams Company; Key City Iron Works; Klauer Manufacturing Company; A. Y. McDonald Manufacturing Company; The Smedley Company

Fairfield.—Dexter Washing Machine Company; Iowa Malleable Iron Company

Fort Madison.—Cushman Machine Works

Iowa City.—Iowa City Iron Works

Marshalltown.—Central Foundry Co.; Lennox Furnace Co.; Victor Furnace Co.; Walter H. Prier Company (brass)

Muscatine.—Muscatine Boiler and Sheet Iron Works; Niver Iron Works

Newton.—Maytag Manufacturing Company; Newton Foundry Company

Oskaloosa.—Ideal Manufacturing Company; Iowa Valve Company.

Ottumwa.—Hardsoeg Manufacturing Company; Ottumwa Iron Works

Perry.—Progressive Foundry

Red Oak.—Kerrihard Company

Sioux City.—Iowa Foundry Company; Sioux City Foundry and Boiler Company

Waterloo.—Hawkeye Foundry Company; Headford Bros. and Hitchins Foundry Company; Swift Manufacturing Company; Waterloo Gasoline Engine Company

CONSUMERS OF WHITE SILICA CORE SAND

Bettendorf.—Zimmerman Steel Company

Fairfield.—Iowa Malleable Iron Company

Keokuk.—Keokuk Steel Casting Company

Waterloo.—Hawkeye Foundry Company

SOURCES OF FOUNDRY SAND USED IN IOWA

Molding Sand.—Iowa Steel and Iron Works, Cedar Rapids; Hart-Parr Company, Charles City; F. A. Chinn, Harrison Road, Clinton; N. Leon Harris, Box 507, Des Moines; Iowa City Iron Works, Iowa City; Lester Williams, 8th St., at Fairgrounds, Marshalltown; J. C. Winebrenner, 904 E. Main, Marshalltown; E. C. Burnside, 306 E. Second St., Muscatine; Ben Lufkin, Reasnor, Jasper county

Core Sand.—C. W. Messer, 534 10th Ave., Clinton; Eddyville Coal Company, Eddyville; Walter H. Prier, Marshalltown; Ottumwa Sand Company, Ottumwa; Iowa Foundry Sand Company, Waterloo.

Silica Sand (For steel molding).—Langworthy Sand Company, Clayton

Blast Sand (For cleaning castings).—Northern Gravel Company, Muscatine

Molding Sand.—Illinois. Akin, Batavia, Collinsville, Dallas City, East Dubuque, Elgin, Galena, Gladstone, Granite City, Milan, Moline, Ottawa, Warren, Wilbur, Wyanet

Indiana. Michigan City

Kansas. Atchison

Michigan. Locality not known

Minnesota. Ottawa

Missouri. Kansas City

Nebraska. Endicott

New York. Albany

Ohio. Conneaut, Sandusky

South Dakota. Sioux Falls

Wisconsin. Beloit, Burlington

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ON A NEW SPECIMEN OF A PALEONISCID BRAIN FROM IOWA

by

ROY L. MOODIE

ON A NEW SPECIMEN OF A PALEONISCID BRAIN FROM IOWA

Table of Contents

Illustrations

Materials

A single nodule, about one-half inch in diameter, picked up on the Rock Island railroad tracks in Iowa City by Mr. William Shurtz and handed to Mr. Herbert Belanski of the University staff and by him to Professor A. O. Thomas at the University, forms the basis for this paper. I am under obligations to Professor Thomas for the opportunity to confirm his identification of the fossilized remains enclosed within the nodule as a part of the cartilaginous* brain case, the brain and semicircular canals of a Paleoniscid fish allied to *Rhadinichthys*. Director G. F. Kay has made the study and publication possible by providing financial aid. Although numerous nodules of this type have been described (see papers by Eastman, Moodie, Parker and Watson) yet the present discovery provides an important new locality for the brain-containing nodules; the nodule itself is split so that the *ventral* aspect of the brain is more clearly shown than in any of the scores of brain-containing nodules examined from the Coal Measures of Kansas (Moodie, '15, '20); it shows that the brain practically fills the brain-

* Watson ('25) states that the endocranium is fully ossified.

case, as Watson ('25) suggested; and it shows something of the brain-case. Any one of these features would justify this description.

It has not been thought feasible to attempt any preparation of the fossil, so it remains as it was found. The nodule bears the catalogue number 13-338 of the Department of Geology, University of Iowa. The drawing (figure 82) is from the pen of the experienced artist, Mr. John L. Ridgway, of the California Institute of Technology at Pasadena.

Historical

I have already given (Moodie, '15) a complete review of the preservation of neural structures, including an annotated bibliography of writings to that date, and there is no need to go over the ground so thoroughly covered. It remains to discuss the contributions of Stensiö ('25) and Watson ('25) on brains and brain case, reserving an account of Stensiö's ('21) and Watson's ('28) writings on the organization of the Paleoniscidae for a later section.

No author has added so richly to our knowledge of neural form among Paleozoic and Triassic vertebrates as has Stensiö. It is not necessary here to add an extensive literature list of Stensiö's ichthyological writings, but I will state that his accounts and illustrations of the brain and nerves of the Upper Silurian (Downtownian) Cephalaspidae and of the Devonian Arthrodire *Macropetalichthys* are without parallel in the realm of vertebrate paleontology.

In Stensiö's ('25, pages 80-81, fig. 17;158; 176-177, fig. 57; 192) discussions of the family Saurichthyidae, allied to the Paleoniscidae, from the Triassic of Spitsbergen, he says:

"On the whole, the brain of the Saurichthyids was of the Actinopterygian type. The telencephalon must have been of about the same order of size as in ordinary teleosts . . . ." This is very pertinent matter in determining the systematic relationships of the ancient family of Paleoniscids, discussed in the next section.

When Doctor Watson visited the United States I discussed with him the nature of the paleoniscid brains and gave him some nodules which I had collected near Baldwin, Kansas. These nodules later (Watson, '25, p. 832) furnished the basis for Watson's determination of a small, but typical and clearly functional myodome of a thoroughly Actinopterygian type (See Watson's figures 9 to 20). This discovery was possible because the bone and cartilage within the nodules was perfectly friable and easily removed with a blunt needle. After the cavity was thoroughly cleaned impressions were made in wax, thus furnishing material for a discussion of the brain case and the myodome, a structure peculiar to fishes, often called the eye-muscle canal, limited to certain teleosts. This is more fully discussed in another section.

The Primitive Sturgeons of the Family Paleoniscidae

The ganoid fishes of the family Paleoniscidae are of extreme interest to paleontologists because during their long geological history from the Devonian to the Jurassic (Dean, '23, p. 622) they were associated with and were related to the Crossopterygian ganoids which gave rise to land vertebrates, the Tetrapoda, and to the air-breathing Dipnoans, on the one hand, and on the other to the family Saurichthyidae, through which they were related to the bony fishes, the Actinopterygians, to which so many modern fishes belong. In fact the cartilaginous ganoids of the later Paleozoic and earlier Mesozoic stood in a strategic position, giving rise to successful characters for all modern, osseous vertebrates, though they themselves failed, dying out either in late Jurassic or early Cretaceous time.

When Woodward published his Catalogue in 1891 more than twenty-five genera were assigned to the group of chondrostean fishes called the Paleoniscidae. The group is known from Europe and North America. Stensiö's memoir ('21) is largely devoted to the Paleoniscidae of the Triassic of Spitsbergen. No revision of the family has been published within recent years.

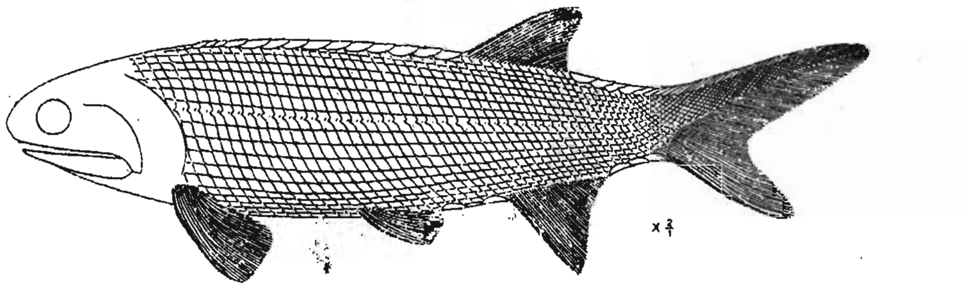

Fig. 80.—Restored outline of the body form, scutellation and fins of *Rhadinichthys alberti* (Jackson), a Paleoniscid ganoid from the Albert shales, Carboniferous, of New Brunswick, Canada. This species is the one most abundantly represented from the Albert shales. It evidently swarmed in countless numbers in the waters of its time. In some of the beds numberless remains of fishes can be attributed to the occasional wholesale destruction of the fishes.—After Lambe.

One genus of the family, *Rhadinichthys* (Hussakof and Bryant, '18; Lambe, '10), is of especial interest (Figure 80) because a nodule containing the head of a fish of this genus from the Mississippian of Kentucky furnished Eastman ('07) and Parker ('07) the material on which the earliest account of the brain was prepared.

The present specimen of a Paleoniscid may belong to the genus *Rhadinichthys,* but there are no characters on which we may base an identification. The nodule itself and the retained brain look like the nodules from the Coal Measures of Kansas (Moodie, '15). It is apparently not possible to say definitely what the geological age of the Iowa specimen is, but I believe it to have been derived from the Coal Measures.

The Paleoniscidae were all rather small fishes, the largest attaining a length of a few inches. Lambe ('10) has written a very splendid account of the conditions under which the Paleoniscidae of New Brunswick were preserved.

The Nodules Containing the Brains

The phosphatic nodules containing the paleoniscid brains are of a somewhat uniform appearance and apparently all have the same structure. None of them exceeds an inch and a half in length by three-quarters inch in breadth. All are apparently derived from calcareous

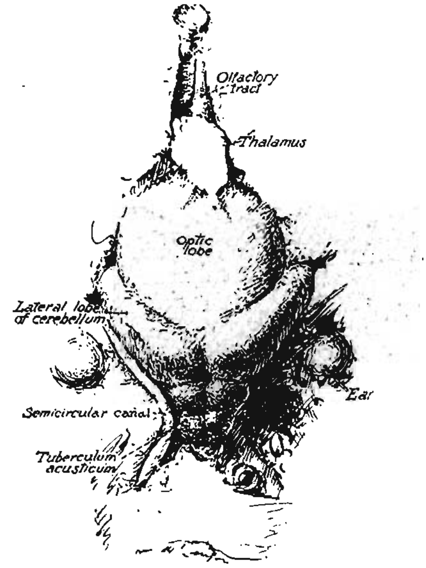

FIG. 81.—The oldest known fossil Paleoniscid brain, drawn with the aid of a reading glass from the original photograph, furnished by Dr. Eastman, natural size, of the specimen of *Rhadinichthys deani* Eastman, a ganoid from the Waverly shales, Mississippian, of Kentucky. The posterior part of the brain has been broken away. At the anterior tip of the olfactory tract is seen a poorly preserved enlargement which may represent the olfactory sac. Enlarged 2.5 times.

shales. Their microscopic structure has been determined (Moodie, '20) but to this day no one knows why such brain-containing nodules refer exclusively to the single family, the Paleoniscidae. Nor has anyone explained why such perfect brains are preserved in these nodules. They are not *casts,* since I have shown that (Moodie, '20) there is a meningeal space filled with interlacing threads of calcite. So far as we know organic structures are not preserved within the brain substance. The present specimen shows a closer approximation of the brain to the brain case, but this is largely due to the fact that the ventral aspect of the brain is exposed, and it is natural to conclude that the inferior brain surface would more nearly approximate the meningeal wall than the superior surface, because of gravity.

The Myodome

The purpose of this section is to call more fully to attention the interesting observations and results of Dr. D. M. S. Watson ('25) on unpromising material—a small series of nodules from the Coal Measures of Kansas. He discovered, described and figured, for the first time, the *myodome* in the fossil family Paleoniscidae. The myodome was clearly functional and indicates the presence of large eye-balls in these small ancient fish. This is substantiated by my earlier (Moodie, '15) discovery of a large orbit, with a large optic nerve foramen leading into it.

The myodome is developed in response to the growth of the rectus muscle of the eye-ball. Its anatomy in recent fishes has been considered at length by Allis ('09, '19). This eye muscle canal of fishes has a counterpart among the higher vertebrates (Allis, '19) and while its occurrence in these Coal Measures fishes has undoubted evolutionary importance, yet its functional adaptation must not be lost sight of. The size and importance of the myodome is to be correlated with the optic lobe.

The Nature of the Brain

The brain of this ancient fish, as in most modern primitive fishes, is essentially a smelling and seeing organ, as is witnessed by the large size of the olfactory tract and the optic lobes (figures 81 and 82).

In spite of the great antiquity of the present specimen, dating as it probably does from the Coal Measures (figure 82), yet the brain is essentially actinopterygian. This means that although the Paleoniscidae were ancient fishes of a primitive organization, they had nevertheless shown strong inclinations toward the bony fishes in such a manner as to exclude them from the stem forms which led to the higher vertebrates, the *tetrapoda.*

Observations on the New Specimen

The new specimen presents the following measurements:

Length of nodule	26 mm.
Width of nodule	24 mm.
Length of brain as preserved	18 mm.
Length of olfactory tract	5.5 mm.
Length of optic lobe	8 mm.
Diameter of hypothalamus	1 mm.
Length of semicircular canals, as preserved	10.5 mm.

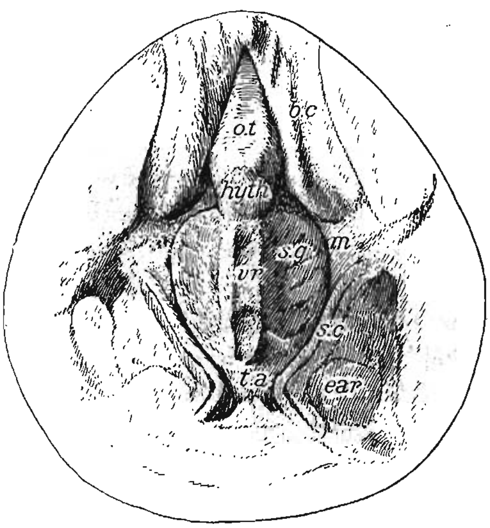

FIG. 82.—The new Paleoniscid brain from the Coal Measures (?) of Iowa. No. 13-338, Department of Geology, University of Iowa. The ventral aspect of the brain is shown anterior to the cerebellar region.
b. c.=brain case (cartilaginous?) represented by very friable granular calcite.
ear=This rounded area, symmetrical on the two sides, may represent the position of the otoliths.
hyth=The nuclear enlargement doubtless represents the hypothalamus.
m=The dark line to the left of the letter "m" represents the thin meninges, greatly reduced on the *ventral* aspect of the brain.
o. t.=The olfactory tract is more elongated than in the brains described from Kansas. The olfactory sac is hidden beneath the fossilized brain wall. Swelling of tract is unique.
s. c.=Semicircular canal, ventral aspect of a vertical canal, ending in ampullary enlargements, obvious only by careful examination under binocular microscope. Canals flattened, less than 1 mm. in diameter.
s. g.=Primitive segmental grooves and ridges. Two narrow prominent ridges on right.
t. a.=Structures ventral to tuberculum acusticum. (See figure 81.)
v. r.=Ventral ridge, broken. Broad T-shaped swelling at the posterior end may represent the ventral continuation of the cerebellum.
Enlarged 2.5 times.

It presents for consideration the *ventral* surface of the brain for the first time since these objects have received attention. The most obvious difference is in the absence of the prominent cerebellar lobes from the ventral surface. The broad T-shaped swelling of the posterior end of the ventral ridge (Fig. 82, v.r.) is assumed to indicate the ventral continuation of the cerebellum. Immediately posterior to this area there is a pronounced constriction and then a moderate expansion.

The optic lobes (Fig. 82) form the largest part of the brain structure preserved. Their ventral surfaces are marked with broad, shallow grooves and sharp, narrow primitive segmental ridges.

The ear is represented by parts of the anterior and posterior vertical semicircular canals on each side and a space which may have been occupied by the otolith (Fig. 82, ear). The canals are flattened and less than 1 mm. in diameter. They end in poorly preserved ampullary enlargements. There is no evidence to show that the otic elements were any different from those of modern fishes.

The meningeal space is fairly narrow, except for such pockets as occur lateral to the hypothalamus (Fig. 82, hyth). The spaces throughout are filled with friable granular calcite. The ventral part of the meningeal spaces would necessarily be narrower than the dorsal, on account of the weight of the brain and the pull of the nerves.

The olfactory tract presents an appearance different from that described in the case of the Kansas specimens (Moodie, '15). Both present a swelling, but the Kansas material shows this nuclear area to have been more localized. The terminal olfactory sac is not shown but doubtless lies below the fossilized brain case. Attempts to expose the sac by removing the friable material would have ended disastrously.

In all other respects the new brain specimen (Fig. 82) corresponds with those described from the Coal Measures (Moodie, '15).

It is possible that the elevation spoken of as the ventral ridge (figure 82, v.r.) is not entirely neural in origin. A part of it may represent the endocranial cast of the floor of the brain case. The ridge itself is, however, so badly broken that this matter cannot be determined from this one specimen.

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MINERAL PRODUCTION IN IOWA
IN 1928 and 1929

by

JAMES H. LEES

MINERAL PRODUCTION IN 1928*

OUTLINE

The mineral industry showed improvement in nearly all its branches during 1928. Quantities and values were greater in cement, coal and stone, and the value of sand and gravel sold was greater even though the quantity was somewhat less. The clay and gypsum working industries showed declines, slight in the case of clay wares but serious in the gypsum products business. These decreases are doubtless to be attributed to tightening of business conditions, resulting in less building, as similar falling off was observed in production of building sand and gravel.

In the United States as a whole mineral production showed little change from 1927. The total value of all products was $5,384,900,000 in 1928 as contrasted with a value of $5,529,500,000 in 1927, a decline of 2 per cent. This decrease was due almost entirely to a lowering in the value of mineral fuels produced. The quantity and value of coal and petroleum decreased, although more gas and natural gasoline were produced. It is interesting to note the relative values of metallic and nonmetallic materials produced in this country. For 1928 these were as follows:

Metallic	**$1,284,580,000**
Nonmetallic except fuels	1,206,158,000
Mineral fuels	2,884,962,000
Others	9,200,000
	$5,384,900,000

* Statistics for clay wares are collected by the Bureau of the Census. Other statistics are collected and compiled by the Bureau of Mines in co-operation with the Iowa Geological Survey.

Mineral Production in Iowa in 1927 and 1928

Product	*Unit*	1927 *quantity*	1927 *value*	1928 *quantity*	1928 *value*
Cement	bbl. 376 lb.	5,661,234	$ 9,124,405	6,880,731	$ 10,734,838
Clay wares			5,194,780		5,048,774
Coal	ton	2,949,622	9,304,000	3,683,635	10,525,000
Gypsum	ton	723,942	6,713,497	719,736	5,355,214
Limestone and lime	ton	1,278,056	1,267,033	1,666,270	1,742,252
Sand and gravel	ton	3,981,143	1,839,176	3,423,619	2,094,955
			33,442,891		35,501,033

CEMENT

The production of Portland cement in Iowa was 31 per cent greater in 1928 than in 1927 and shipments were 22 per cent greater. This increase may be attributed in part, no doubt, to the state's extensive road-making program, which involves the building of a great number of cement culverts and bridges as well as the paving of many miles of roadway. Improved business conditions permitted resumption of operation at the Gilmore City plant of the Northwestern States Portland Cement Company, which had been idle for two years. With the reopening of this plant all six factories of the state were in operation. Three of the plants, the newer ones, use the wet process of manufacture, while the others use the dry process. Even with improved conditions production and shipments were far below the real capacity of the plants, as is shown by the figures given below.

The manufacturing district that includes Iowa, eastern Missouri, Minnesota and South Dakota increased production by 16 per cent and shipments by 14 per cent in 1928 over 1927, although the average price per barrel declined from $1.60 to $1.56. Figures for production in Iowa follow.

Production of Cement in Iowa

	1926	1927	1928
Production, bbls.	4,925,811	5,415,144	7,070,172
Stock, Dec. 31, bbls.	1,616,842	1,370,481	1,559,925
Shipments, bbls.	4,788,639	5,661,234	6,880,731
Shipments, value	$8,167,341	$9,124,405	$10,734,838
Average factory price per bbl.	$1.71	$1.61	$1.56
Consumption, bbls., Est.	2,826,839	3,708,471	5,348,807
Consumption per capita, bbls., Est.	1.17	1.53	2.20
Surplus production, bbls.	1,961,800	1,952,763	1,531,924
Annual capacity, bbls.	6,575,000	7,935,000	9,593,000

Shipments of cement from mills into Iowa by months in 1928 were as follows:

Jan.	30,488	Apr.	405,654	July	873,528	Oct.	442,740
Feb.	41,520	May	929,356	Aug.	813,328	Nov.	96,294
Mar.	149,705	June	790,414	Sept.	738,450	Dec.	34,397

Some statistics for the United States in 1928 are given herewith:

States	Plants	Production	Shipments		Aver. fact. price per bbl.
		bbls.	*bbls.*	*value*	
Alabama	6	6,749,202	6,696,684	$ 8,233,872	$ 1.23
California	12	13,555,579	13,699,851	25,906,942	1.89
Illinois	4	7,334,833	7,405,667	11,602,848	1.57
Iowa	6	7,070,172	6,880,731	10,734,838	1.56
Kansas	7	6,574,219	6,787,568	10,091,330	1.49
Michigan	14	13,848,561	14,044,230	19,268,707	1.37
Missouri	5	7,881,118	7,943,367	12,367,018	1.56
Ohio	10	9,233,033	9,364,338	14,928,183	1.59
Pennsylvania	26	41,522,401	41,161,019	62,572,588	1.52
Tennessee	6	4,689,703	4,634,280	6,322,213	1.36
Texas	7	6,345,604	6,231,083	10,938,646	1.76
Other States	53	51,494,421	50,989,514	83,005,760	1.63
Totals	156	176,298,846	175,838,332	275,972,945	1.57
1927	153	173,206,513	171,864,728	278,854,647	1.62

Consumption of fuel for cement making in the United States in 1928 was: Anthracite coal, 210,390 tons; bituminous coal, 9,592,041 tons; oil, 3,508,038 barrels of 42 gallons; natural gas, 30,660,348,200 cubic feet. The use of fuel per barrel of cement (376 pounds) produced was: Coal, 131.1 pounds; oil, 0.2495 barrel; natural gas, 2,133.7 cubic feet. Dry process plants burning coal used 122 pounds per barrel of cement, while wet process plants used 148 pounds per barrel. Dry process plants burning oil used 10 gallons per barrel of finished cement and wet process plants used 11.2 gallons per barrel of cement.

CLAY WARES

The output of brick of various kinds was somewhat greater in 1928 than in 1927, but as prices were lower the value was less. Just the opposite conditions prevailed in the case of hollow ware, as the output was less but the value greater. However, the total value of the output was somewhat less than in 1927 and fewer plants were active. It seems that the manufacture of clay products is being concentrated more and more in the larger plants of the state, presumably those that have easily accessible and large deposits of high grade clay and that are close to large markets. In 1928 forty-eight plants located in 30 counties were operated as compared with 55 plants in 33 counties in 1927. Because of the small number of plants it is necessary to combine the statistics of most of the counties, as very few counties have three or more producers. It should be noted, perhaps, that in the table showing output by counties the total at the foot of each column is not the sum of the items given in the column, as it was necessary in several cases to transfer items from one column to another. The totals given are those actually applying to the classes of ware named in the different columns.

The first table here given shows the production in 1927 and 1928 grouped by classes of materials. The second shows output by counties in 1928.

Production of Clay Wares by Classes

Class	1927			1928		
	No.	*quan. thous.*	*value*	*No.*	*quan. thous.*	*value*
Common brick	36	51,885	$ 564,425	40	57,224	$ 640,684
Face brick	20	23,720	397,945	23	19,449	359,366
Hollow and vitrified brick	8	14,448	257,325	4	14,343	140,803
Hollow building tile						
(a) Partition, load-bearing, furring, book tile	30	*tons* 232,575	1,363,354	35	*tons* 235,148	1,623,247
(b) Floor-arch, silo, and corn crib tile; conduits; radial chimney blocks; fire-proofing	10	60,486	403,299	9	52,798	398,969
Drain tile	41	176,404	1,167,542	37	130,235	1,018,074
Sewer pipe	4	65,322	913,676	4	52,639	715,233
Flue lining	4	3,925	46,778	4	4,599	49,101
Wall coping	4	972	17,924	4	868	13,252
Floor tile, segment blocks, flower pots, other ware	7		45,996	7		68,025
Clay sold	3	2,828	15,216	4	2,339	22,020
	55		5,194,780	48		5,048,774

The Bellevue pottery continues the manufacture of red earthenware flower pots and similar ware. The clay sold raw is mostly classed as fire clay, although a little is of finer grade and is said to be used in soaps. Clay sales in the United States in 1928 amounted to $12,200,-739, to which fire clay contributed $7,480,609, kaolin, $4,088,003, and other kinds lesser amounts.

Production of Clay Wares in Iowa in 1928

Counties	No. Producers	Brick (a)		Hollow ware (b)		Drain tile, sewer pipe, other products (c)		Total Value
		thous.	*value*	*tons*	*value*	*tons*	*value*	
Allamakee (1), Dubuque (1), Fayette (1), Floyd (1)	4	2,919	$ 36,826	20,632	$ 147,168	(d)		$ 183,994
Appanoose (1), Henry (1), Jefferson (1), Johnson (1)	4	677	8,972	2,157	17,151			26,123
Audubon (2) Woodbury (2)	4	22,531	254,468	4,794	32,523			286,991
Benton (1), Grundy (1), Hardin (1), Tama (2), Wright (1)	6	2,276	33,590	(e)		1,714	$ 15,900	49,490
Cerro Gordo (2), Franklin (1)	3	6,656	88,135	152,121	1,103,492	46,526	370,805	1,562,442
Dallas	4	4,747	72,110	44,002	299,143	23,490	198,032	569,285
Jackson (1), Scott (1), Washington (1)	3	(d)		2,000	34,378	(d)		34,378
Jasper (1), Mahaska (2), Poweshiek (1)	4	7,800	76,959	(f)		807	6,053	83,012
Keokuk	3	(e)		(e)		17,860	195,969	195,969
Polk	4	19,073	297,310	19,505	589,023	15,180	163,290	589,023
Story (1), Wapello (1), Warren (1)	3	3,629	43,787	18,574	127,388	8,792	64,478	235,653
Webster	6	20,597	236,449	35,563	247,683	65,496	758,292	1,232,424
Total for 1928	48	91,016	1,140,853	287,946	2,022,216	182,874	1,885,705	5,048,774
Total for 1927	55	90,053	1,219,695	293,061	1,766,653	251,000	2,208,432	5,194,780

(a) Includes: Common brick, face brick, hollow brick, paving and other vitrified brick.
(b) Includes: Partition, load-bearing, floor arch, silo and corn crib tile, fire-proofing, etc.
(c) Includes: Floor tile, flue lining, wall coping, segment blocks, other products, pottery, raw clay.
(d) Included in Hollow Ware.
(e) Included with Drain Tile.
(f) Included with Brick.

The leading states of the Union in the making of clay wares in 1928 were these:

State	Brick and tile	Pottery	Total
California	$ 16,721,960	$ 4,271,387	$ 20,993,347
Illinois	26,328,670	5,698,215	32,026,885
Indiana	12,932,816	3,613,895	16,546,711
Iowa	5,048,774		5,048,774
Kentucky	6,954,582	158,941	7,113,523
Michigan	3,019,297	3,291,289	6,310,586
Missouri	14,891,273		14,891,273
New Jersey	18,160,009	21,219,269	39,379,278
New York	15,422,513	7,051,892	22,474,405
Ohio	47,867,039	33,981,383	81,848,422
Pennsylvania	40,861,414	7,067,389	47,928,803
Texas	5,992,538	184,264	6,176,802
West Virginia	5,019,880	14,007,665	19,027,545
Total for United States	$265,770,513	$107,780,369	$373,550,882

COAL

The coal industry began its laborious climb out of the slough of despond in which the strike of 1927 had left it, and production increased materially over that of the preceding year. While the output was not equal to that before the strike its increase shows that the industry is once more on a good footing. Brightening prospects have increased the number of mines, particularly the smaller ones, whose owners are not able to continue operations when conditions become adverse. It is unfortunate for Iowa, however, that as a result of the strike the Superior Coal Company closed its mines in this state and has withdrawn from the Monroe county field. As this was for many years the leading producer in the county, and indeed in the state, its removal affects Monroe county's production seriously. For several years Marion county has held the lead which Monroe had for so long, because of the opening of the rich Marion county fields by the Consolidated Indiana, Pershing and Red Rock Coal Companies at the same time that the large operators of Monroe county were approaching the end of their activities. In 1918 Monroe's coal output was 2,317,900 tons, as compared with 351,764 tons in 1928. Marion county's output in the same years was 609,266 tons and 848,294 tons respectively.

Large gains were made in 1928 over the preceding year by Appanoose, Lucas, Marion and Warren counties. While only Marion and Polk are now in the one-half-million tons class, as compared with three counties which produced over a million tons each in 1918, yet

*Production, Value, Men Employed, Days Worked, and Output per Man per Day at Coal Mines in Iowa in 1928.**
(Exclusive of product of wagon mines producing less than 1,000 tons)

County	No. Producers	Net tons				Value		Number of employees			Average number of days worked	Average tons per man per day
		Loaded at mines for shipment	Sold to local trade and used by employees	Used at mines for steam and heat	Total quantity	Total	Average per ton	Underground	Surface	Total		
Adams (4) and Page (2)	6	....	31,952	....	31,952	$ 96,000	$ 3.00	54	5	59	233	2.32
Appanoose	59	394,772	69,629	885	465,286	1,310,000	2.82	1,313	109	1,422	159	2.06
Boone	5	323,633	70,860	3,383	397,876	1,460,000	3.67	868	47	915	171	2.54
Dallas	6	272,394	8,469	1,178	282,041	810,000	2.87	593	47	640	139	3.16
Davis (1), Jefferson (2), and Keokuk (1)	4	....	4,760	10	4,770	17,000	3.56	21	3	24	102	1.94
Greene (2) and Webster (2)	4	....	9,239	240	9,479	33,000	3.48	24	4	28	168	2.01
Guthrie	7	....	9,131	....	9,131	36,000	3.94	36	4	40	124	1.84
Jasper	8	3,741	41,066	2,815	47,622	137,000	2.88	84	13	97	149	3.30
Lucas	4	300,710	28,087	8,838	337,635	1,020,000	3.02	391	34	425	161	4.93
Mahaska	28	....	52,241	86	52,327	138,000	2.64	137	10	147	152	2.34
Marion	19	776,173	54,695	17,426	848,294	2,017,000	2.38	919	56	975	213	4.08
Monroe	12	321,889	25,498	4,377	351,764	942,000	2.68	649	52	701	174	2.89
Polk	15	298,107	269,633	7,614	575,354	1,688,000	2.93	860	69	929	206	3.00
Taylor	3	4,206	11,118	....	15,324	63,000	4.11	51	3	54	175	1.62
Van Buren	6	4,285	5,954	100	10,339	31,000	3.00	30	1	31	154	2.17
Wapello	21	3,281	58,163	....	61,444	182,000	2.96	139	13	152	154	2.63
Warren	5	146,157	10,691	5,945	162,793	481,000	2.95	239	25	264	176	3.50
Wayne	4	....	20,204	....	20,204	64,000	3.17	57	5	62	161	2.02
Total for 1928	215	2,849,348	781,390	52,897	3,683,635	10,525,000	2.86	6,465	500	6,965	175	3.02
Totals for 1927	176	2,146,788	746,755	56,079	2,949,622	9,304,000	3.15	8,085	656	8,741	114	2.96

* The figures relate only to active mines of commercial size that produced coal in 1928. The number of such mines in Iowa was 222 in 1928; 183 in 1927; and 193 in 1926.

Methods of mining in 1928: The tonnage by hand was 379,742, 10.3 per cent; shot off the solid, 2,030,875, 55.1 per cent; cut by machines, 1,199,538, 32.6 per cent; not specified, 73,480, 2 per cent.

Size classes of commercial mines in 1928: There were 4 mines in Class 1 B (200,000 to 500,000 tons) producing 1,182,582 tons or 32.1 per cent of the tonnage; 5 in Class 2 (100,000 to 200,000 tons) with 784,590 tons or 21.3 per cent; 6 in Class 3 (50,000 to 100,000 tons) with 417,609 tons or 11.3 per cent; 34 in Class 4 (10,000 to 50,000 tons) with 878,795 tons or 23.9 per cent; 173 in Class 5 (less than 10,000 tons) producing 420,059 tons or 11.4 per cent.

the record of these counties indicates a gradual increase in output and use of Iowa coal.

The output per day, 3.02 tons, was the highest of any recent year except 1925, when it was the same as this year. The output per man per year, 525 tons, also was the highest except for 1920, when it was 653 tons. The average tonnage per underground man in 1928 was 3.26 per day or 570 per year.

Iowa has been somewhat laggard in the use of machinery in mining coal. In 1913 there were 28 coal cutting machines and in 1927 this number had risen to 93, but in 1928 only 84 were in use. The percentage of coal cut by machines in 1928, which was 32.6, does not compare very favorably with that so mined in other leading coal producing states, such for instance as 64 in Alabama, 56 in Colorado, 75 in Illinois, 90 in Kentucky, 68 in Pennsylvania, 85 in Virginia and West Virginia.

It may be of interest to note, although it is not flattering to state pride, that Iowa ranked next to the bottom in the percentage of coal produced the value of which was actually reported to the Bureau of Mines in 1928. The percentage was 74.05 and the lowest state was Oklahoma with a percentage of 58.72.

ANALYSES OF IOWA COAL

In 1928 the Iowa Geological Survey collected 36 one-gallon samples of coal from mines widely distributed over the coal-producing districts of this state. These samples were gathered by the most approved methods and were sent to the chemical laboratory of the State University of Iowa. There they were subjected to analysis and to various tests. Some of the results of this work were published by the Survey in technical bulletins and the more important data are reproduced here in order to put them in more permanent form.

Table I, Names and Location of Mines Sampled

No.

1.—Des Moines Ice & Fuel Co., Des Moines, Polk Co.
2.—Bennett Bros. Coal Co., Mine No. 2, Des Moines, Polk Co.
3.—Economy Coal Co., Des Moines, Polk Co.
4.—Des Moines Coal Co., Mine No. 4, Des Moines, Polk Co.
5.—Urbandale Coal Co., Des Moines, Polk Co.
6.—Beck Coal & Mining Co., Des Moines, Polk Co.
7.—Shuler Coal Co., Waukee, Dallas Co.
8.—Gibson Coal Co., Rider, Polk Co.
9.—Great Western Coal Co., Orillia, Warren Co.
10.—Indian Valley Gloss Coal Co., Hartford, Warren Co.
11.—Norwood White Coal Co., No. 8, Herrold, Polk Co.
12.—Norwood White Coal Co., No. 7, Moran, Dallas Co.

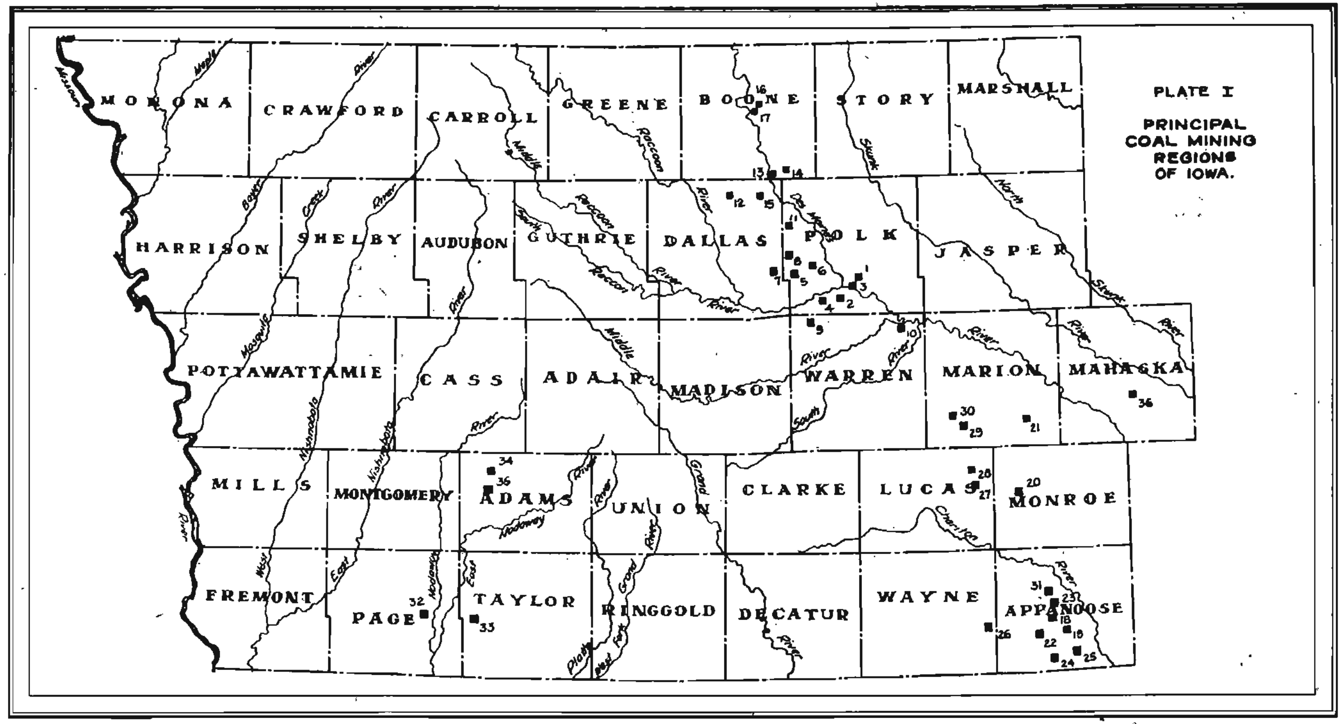


PLATE I

PRINCIPAL COAL MINING REGIONS OF IOWA.

13.—Scandia Coal Co., No. 4, Madrid, Boone Co.
14.—Scandia Coal Co., No. 6. Madrid, Boone Co.
15.—Dallas Products Co., Granger, Dallas Co.
16.—Benson Coal Co., No. 1, Boone, Boone Co.
17.—Boone Coal Co., No. 1, Boone, Boone Co.
18.—Old King Coal Co., Centerville, Appanoose Co.
19.—Center Coal Co., Centerville, Appanoose Co.
20.—Superior Coal Co., No. 19, Bucknell, Monroe Co.
21.—Pershing Coal Co., No. 12, Pershing, Marion Co.
22.—Numa Coal Co., Appanoose Co.
23.—Appanoose Co. Coal Co., Centerville, Appanoose Co.
24.—Armstrong Coal Co., Cincinnati, Appanoose Co.
25.—Iowa Block Coal Co., Exline, Appanoose Co.
26.—Violet Valley Coal Co., Seymour, Wayne Co.
27.—Central Iowa Fuel Co., No. 5, Williamson, Lucas Co.
28.—Central Iowa Fuel Co., No. 4, Williamson, Lucas Co.
29.—Red Rock Coal Co., Melcher, Marion Co.
30.—Consolidated Indiana Coal Co., No. 2, Melcher, Marion Co.
31.—Liberty Coal Co., No. 3, Mystic, Appanoose Co.
32.—Pearson Coal Co., No. 2, Clarinda, Page Co.
33.—New Market Coal Co., New Market, Taylor Co.
34.—John G. Henton Mine, R. F. D. No. 1, Carbon, Adams Co.
35.—Ruth Coal Co., Carbon, Adams Co.
36.—Oskaloosa Coal & Mining Co., Oskaloosa, Mahaska Co.

In presenting Table II, which gives analytical data on the so-called "as received" basis, we wish first to call attention to the moisture content column. As explained above, in collecting the sample the water in the coal is carefully conserved so that it may be measured in the laboratory, but it should be clearly understood that in no wise does this figure represent the moisture percentage of the coal delivered to the consumer after having been in contact with drying air for days or weeks while in transit or storage. The actual moisture value of a coal at a given time is of course dependent upon the humidity of the air and upon the time of exposure to it. It is difficult therefore to estimate how much moisture these coals would contain under marketing conditions, but it is safe to say that the percentages are vastly lower than those given for mine conditions. With lower total moisture values the percentage contents of the other constituents, and also the thermal values, increase in proportion.

Table II, Results of Analyses of Iowa Coals

As Received						
No.	Moisture	Ash	Volatile	Fixed carbon	Thermal values (B. t. u.)	Sulfur
1.	16.0	8.7	37.3	37.9	10,820	5.3
2.	16.8	14.5	35.0	33.7	9,190	5.8
3.	15.9	9.2	37.1	37.7	10,530	5.0
4.	13.8	16.9	34.3	34.9	9,040	5.6
5.	14.2	13.0	36.3	36.5	10,220	5.2
6.	16.7	15.5	33.0	34.7	9,660	3.8
7.	14.2	12.7	34.7	38.3	10,450	3.9
8.	13.7	6.5	39.5	40.3	11,450	3.7

Table II (Continued)

No.	Moisture	Ash	Volatile	Fixed carbon	Thermal values (B. t. u.)	Sulfur
9.	13.1	14.6	35.4	36.8	10,210	6.3
10.	14.6	10.6	39.1	35.7	10,830	4.8
11.	13.6	14.6	36.8	35.0	10,050	5.2
12.	16.9	12.3	33.9	36.9	9,920	3.1
13.	14.9	10.3	36.9	37.8	10,450	3.5
14.	15.1	12.5	36.9	35.5	10,050	4.1
15.	16.2	14.0	34.5	35.3	9,690	3.8
16.	20.9	8.5	33.8	36.7	9,430	4.0
17.	19.7	9.3	36.3	34.7	9,740	4.8
18.	18.1	8.6	33.9	39.4	10,050	3.7
19.	18.0	6.5	35.7	39.7	10,430	2.7
20.	14.8	9.8	35.0	40.4	10,700	2.1
21.	17.1	9.4	34.9	38.6	10,490	3.5
22.	17.6	11.0	36.7	34.7	9,880	4.5
23.	15.3	12.2	34.6	37.9	9,960	3.9
24.	13.4	10.3	35.6	40.7	10,490	4.9
25.	14.9	9.7	36.3	39.1	10,750	3.4
26.	16.7	8.3	34.1	40.8	10,350	3.9
27.	15.8	14.0	33.6	36.5	9,950	5.3
28.	19.8	12.8	32.7	34.6	9,460	2.0
29.	18.5	10.4	32.6	38.5	10,000	2.6
30.	18.6	9.2	31.9	40.2	10,030	2.6
31.	15.6	11.0	35.2	38.2	9,800	3.3
32.	18.4	13.7	35.3	32.6	9,440	3.4
33.	20.2	13.3	33.6	32.9	9,080	5.5
34.	21.1	9.9	32.9	36.1	9,280	3.5
35.	20.6	12.3	33.0	34.1	9,270	3.1
36.	18.1	10.0	33.5	38.4	10,610	2.0
Mean	16.6	11.4	35.0	37.0	10,040	3.9

Table IV, in which the results of the preceding table are calculated to the dry basis, needs no comment except perhaps in explanation of the term "unit coal." This in brief is a hypothetical material intended to represent the pure or actual coal substance calculated from analytical data after taking into consideration corrections for moisture and ash. As developed by Parr the formula is

$$\text{Unit coal} = 1.00 - (W + 1.08\ A + \frac{22}{40} S)$$

where W, A and S are total water, ash as weighed and sulfur respectively.

This "unit coal" value which represents the decomposition residue of a flora characteristic of a given period and region should, if the history of the seam formation is normal, be fairly constant for that given seam. This has proved to be the case particularly where the coal measures are of comparatively large area, as in Illinois. A tabulation of unit coal values of the three beds represented in this study (see tabulation by Lees in table No. VII) shows rather wide variation and it is evident that calculated heating values of a sample from the given bed, based on average unit coal value for that bed, would not be highly accurate. The mean values of the figures in question are given in the following table:

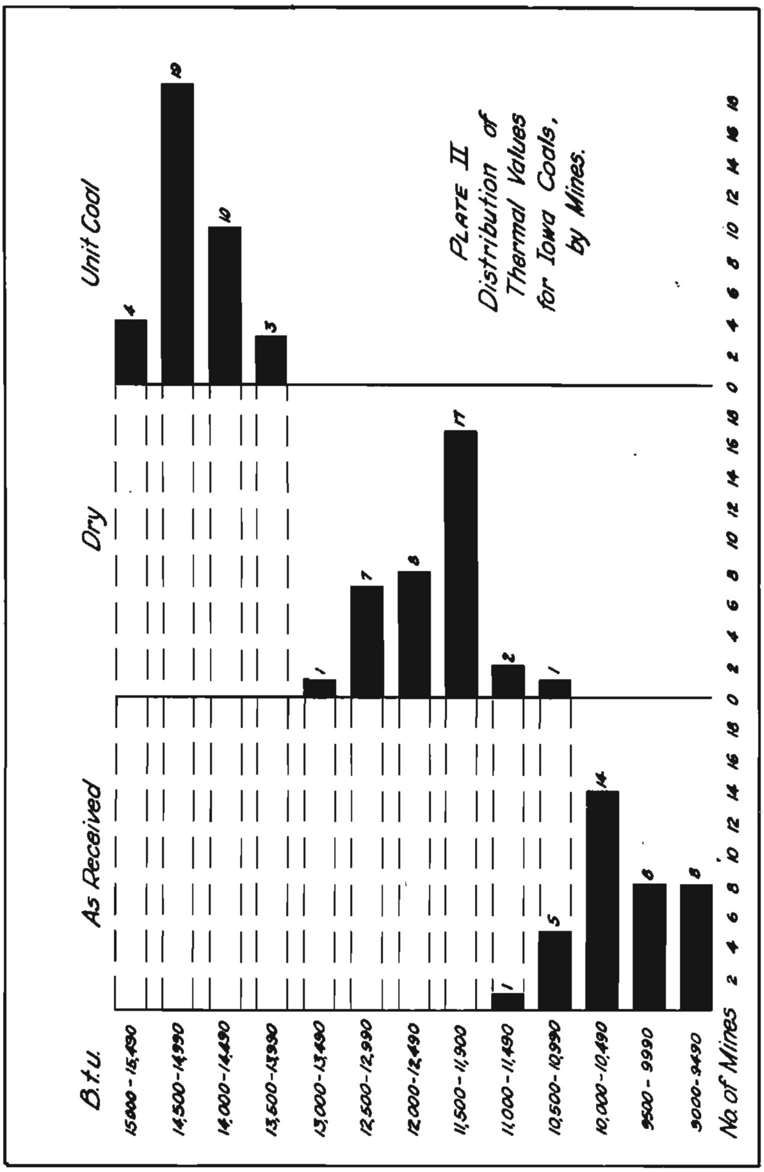
Table III, Average Unit Coal Values of Iowa Coal Beds

Lower Cherokee bed	14,671 B. t. u.
Mystic bed	14,345 B. t. u.
Nodaway bed	14,365 B. t. u.

Table IV, Results of Analyses of Iowa Coals

DRY BASIS						
No.	Ash	Volatile	Fixed carbon	Thermal values (B. t. u.)	Sulfur	Unit coal
1.	10.4	44.5	45.4	12,900	6.3	15,110
2.	17.4	42.1	40.5	11,050	7.0	14,290
3.	11.0	44.2	44.9	12,550	5.9	14,730
4.	19.6	39.8	40.6	10,500	6.5	13,950
5.	15.2	42.3	42.5	11,910	6.1	14,760
6.	18.6	39.7	41.7	11,600	4.6	14,970
7.	14.8	40.5	44.7	12,200	4.6	14,950
8.	7.5	45.8	46.7	13,260	4.3	14,830
9.	16.8	40.8	42.4	11,750	7.3	15,100
10.	12.4	45.8	41.8	12,620	5.6	15,110
11.	16.9	42.6	40.5	11,630	6.0	14,850
12.	14.8	40.8	44.4	11,940	3.7	14,560
13.	12.1	43.4	44.5	12,300	4.1	14,550
14.	14.7	43.5	41.8	11,840	4.8	14,530
15.	16.7	41.2	42.1	11,560	4.6	14,550
16.	10.8	42.8	46.4	11,950	5.1	13,990
17.	11.6	45.2	43.2	12,130	6.0	14,430
18.	10.5	41.4	48.1	12,270	4.5	14,270
19.	7.9	43.6	48.5	12,730	3.3	14,210
20.	11.5	41.1	47.4	12,550	2.5	14,550
21.	11.3	42.1	46.6	12,650	4.2	14,800
22.	13.3	44.6	42.1	11,990	5.5	14,520
23.	14.4	40.9	44.7	11,750	4.7	14,360
24.	11.9	41.2	46.9	12,120	5.6	14,430
25.	11.5	42.6	45.9	12,630	4.0	14,790
26.	9.9	40.7	49.4	12.420	4.7	14.330
27.	16.6	39.9	43.5	11,810	6.3	15,020
28.	15.9	40.6	43.5	11,810	2.5	14,510
29.	12.8	39.9	47.3	12,260	3.1	14,510
30.	11.3	39.1	49.6	12,330	3.2	14,330
31.	13.0	41.7	45.3	11,620	4.0	13,870
32.	16.7	43.2	40.1	11,560	4.2	14,500
33.	16.7	42.0	41.3	11,380	7.0	14,570
34.	12.5	41.6	45.9	11,760	4.5	14,000
35.	15.5	41.6	42.9	11,680	3.9	14,390
36.	12.2	40.9	46.9	12,960	2.4	15,140
Mean	13.6	42.0	44.4	12,045	4.8	14,555

Plate II gives a graphical analysis of all the preceding data wherein thermal values are plotted as ordinates against the number of mines from which samples having these thermal values were obtained.



It is interesting to compare the results of this and of Hixson's survey (in Vol. XIX) with those of a similar one from an adjoining state. From a list compiled by Parr from Bull. No. 29, Illinois State Geological Survey, which gives figures on 36 samples of coal from 29 different counties, we have calculated the Illinois data given in the table below.

Table V, Comparative Data on Iowa and Illinois Coals

MEAN VALUES (DRY BASIS)				
	Volatile matter	Ash	Sulfur	Thermal value
Iowa (36 samples)	42.0	13.6	4.8	12,045 B.t.u.
Iowa (16 samples)	40.1	13.7	4.9	12,552 B.t.u. (Hixson)
Illinois (36 samples)	37.3	11.0	3.7	12,725 B.t.u.

Total moisture contents on the wet basis were for the Iowa and Illinois coals 13.6, 15.1 and 12.4 respectively. It may be seen, therefore, that so far as proximate analyses can be relied upon to distinguish them, the difference is much less than is often popularly supposed.

FUSION TEMPERATURES OF IOWA COAL ASH

Because of the important bearing ash fusion temperatures have on the formation of slag and clinker in the coal furnace a systematic study was made of this phase of the problem.

The samples tested were from the coals described above. Quantities of the coal, 50 to 100 grams in weight, were ground to 60 mesh and burned in a gas fired muffle furnace. The ash was ground in an agate mortar and again heated to 1600 degrees F. in a stream of oxygen to insure the highest oxidation of all the mineral constituents. The finished material was then fashioned into small cones and heated in a special gas fired furnace under reducing conditions up to the softening points of the ash.

Temperatures were measured by means of an optical pyrometer of modern design.

Table VI, Melting Points of Iowa Coal Ash Degrees Fahrenheit

Numbers refer to samples as listed in Table I. Tests were made with a standard gas furnace under reducing conditions and temperatures were measured with an F. and F. optical pyrometer.

Number	Temperature	Number	Temperature
1	2063	19	2023
2	1981	20	2168
3	1940	21	1937
4	2035	22	1930
5	1935	23	2000
6	2063	24	1930
7	1947	25	1998
8	2033	26	1945
9	2025	27	1946
10	2193	28	2055
11	2177	29	2000
12	2192	30	1957
13	1960	31	2148
14	2353	32	2253
15	2005	33	2237
16	2037	34	2238
17	1889	35	1985
18	1980	36	2040

A final word may be said concerning the comparison of the values obtained in this work with those based on the analysis of the same, or similar coals made at other laboratories.

As we have already explained, all sampling for these studies was made by a member of the Geological Survey acting of course as an unbiased referee. The method used is both the most fair and the most severe, inasmuch as it provides for the inclusion of impurities in their proper proportions and precludes the possibility of either premeditated or unconscious "handpicking", which is a major factor in vitiating results. It follows, therefore, that comparisons between our figures and others can be made fairly, only when all are reduced to a common standard of sampling, analysis and calculation.

GEOGRAPHIC DISTRIBUTION OF SAMPLES

In the following table the mines which were sampled are arranged geographically from north to south so that the analyses of coals from different districts and from different beds can be more readily compared. The mines in the Mystic (or Centerville) bed are arranged from east to west; those in the Nodaway bed from north to south. Compare also Plate I. The first line following each mine number is the analysis "as received"; the next line represents the analysis "bone dry".

Table VII, Composition of Iowa Coals Tabulated by Beds

Lower Cherokee Beds							
No.	Moisture	Ash	Volatile	Fixed carbon	B. t. u.	Sulfur	Unit coal
16.	20.98	8.5	33.8	36.7	9,430	4.0	
		10.8	42.8	46.4	11,950	5.1	13,990
17.	19.72	9.3	36.3	34.7	9,740	4.8	
		11.6	45.2	43.2	12,130	6.0	14,430
13.	14.97	10.3	36.9	37.8	10,450	3.5	
		12.1	43.4	44.5	12,300	4.1	14,550
14.	15.11	12.5	36.9	35.5	10,050	4.1	
		14.7	43.5	41.8	11,840	4.8	14,530
12.	16.94	12.3	33.9	36.9	9,920	3.1	
		14.8	40.8	44.4	11,940	3.7	14,560
15.	16.24	14.0	34.5	35.3	9,690	3.8	
		16.7	41.2	42.1	11,560	4.6	14,550
11.	13.64	14.6	36.8	35.0	10,050	5.2	
		16.9	42.6	40.5	11,630	6.0	14,850
7.	14.25	12.7	34.7	38.3	10,450	3.9	
		14.8	40.5	44.7	12,200	4.6	14,950
8.	13.74	6.5	39.5	40.3	11,450	3.7	
		7.5	45.8	46.7	13,260	4.3	14,830
5.	14.24	13.0	36.3	36.5	10,220	5.2	
		15.2	42.3	42.5	11,910	6.1	14,760
6.	16.78	15.5	33.0	34.7	9,660	3.8	
		18.6	39.7	41.7	11,600	4.6	14,970

Table VII (Continued)

No.	Moisture	Ash	Volatile	Fixed carbon	B. t. u.	Sulfur	Unit coal
9.	13.17	14.6	35.4	36.8	10,210	6.3	
		16.8	40.8	42.4	11,750	7.3	15,100
4.	13.89	16.9	34.3	34.9	9,040	5.6	
		19.6	39.8	40.6	10,500	6.5	13,950
2.	16.82	14.5	35.0	33.7	9,190	5.8	
		17.4	42.1	40.5	11,050	7.0	14,290
3.	15.99	9.2	37.1	37.7	10,530	5.0	
		11.0	44.2	44.9	12,550	5.9	14,730
1.	16.05	8.7	37.3	37.9	10,820	5.3	
		10.4	44.5	45.4	12,900	6.3	15,110
10.	14.6	10.6	39.1	35.7	10,830	4.8	
		12.4	45.8	41.8	12,620	5.6	15,110
30.	18.65	9.2	31.9	40.2	10,030	2.6	
		11.3	39.1	49.6	12,330	3.2	14,330
29.	18.52	10.4	32.6	38.5	10,000	2.6	
		12.8	39.9	47.3	12,260	3.1	14,510
28.	19.89	12.8	32.7	34.6	9,460	2.0	
		15.9	40.6	43.5	11,810	2.5	14,510
27.	15.88	14.0	33.6	36.5	9,950	5.3	
		16.6	39.9	43.5	11,810	6.3	15,020
21.	17.12	9.4	34.9	38.6	10,490	3.5	
		11.3	42.1	46.6	12,650	4.2	14,800
20.	14.80	9.8	35.0	40.4	10,700	2.1	
		11.5	41.1	47.4	12,550	2.5	14,550
36.	18.1	10.0	33.5	38.4	10,610	2.0	
		12.2	40.9	46.9	12,960	2.4	15,140
				Mystic Bed			
19.	18.09	6.5	35.7	39.7	10,430	2.7	
		7.9	43.6	48.5	12,730	3.3	14,210
25.	14.94	9.7	36.3	39.1	10,750	3.4	
		11.5	42.6	45.9	12,630	4.0	14,790
24.	13.42	10.3	35.6	40.7	10,490	4.9	
		11.9	41.2	46.9	12,120	5.6	14,430
22.	17.62	11.0	36.7	34.7	9,880	4.5	
		13.3	44.6	42.1	11,990	5.5	14,520
18.	18.14	8.6	33.9	39.4	10,050	3.7	
		10.5	41.4	48.1	12,270	4.5	14,270
23.	15.32	12.2	34.6	37.9	9,960	3.9	
		14.4	40.9	44.7	11,750	4.7	14,360
31.	15.61	11.0	35.2	38.2	9,800	3.3	
		13.0	41.7	45.3	11,620	4.0	13,870
26.	16.76	8.3	34.1	40.8	10,350	3.9	
		9.9	40.7	49.4	12,420	4.7	14,330
				Nodaway Bed			
34.	21.1	9.9	32.9	36.1	9,280	3.5	
		12.5	41.6	45.9	11,760	4.5	14,000
35.	20.6	12.3	33.0	34.1	9,270	3.1	
		15.5	41.6	42.9	11,680	3.9	14,390
33.	20.2	13.3	33.6	32.9	9,080	5.5	
		16.7	42.0	41.3	11,380	7.0	14,570
32.	18.4	13.7	35.3	32.6	9,440	3.4	
		16.7	43.2	40.1	11,560	4.2	14,500

In the United States as a whole coal production was on a lower level than in 1927. It amounted to 500,744,970 tons of bituminous coal, a decrease of 3.3 per cent from the year before. The number of active commercial mines and the number of men employed also decreased notably. In 1928 the operating mines totaled 6,450, a loss of 561 from the previous year, and the labor force was reduced 71,768, the total in 1928 being 522,150 men. The number of days worked per man in 1928 was 203, an improvement of 12 over 1927, and the daily output per man was 4.73 tons, a gain over 1927 of 0.18 ton and an increase of 1.12 tons since 1913.

The following tables give some salient statistics regarding bituminous coal production in the leading states:

State	Rank	Tons	Value	Av. Val.	Men	Tons per man daily
West Virginia	1	132,952,159	$ 211,480,000	$1.59	111,733	5.35
Pennsylvania	2	131,202,163	249,895,000	1.90	133,414	4.52
Kentucky	3	61,860,379	96,722,200	1.56	62,195	4.69
Illinois	4	55,948,199	112,095,000	2.00	64,266	5.57
Alabama	5	17,621,362	39,601,000	2.25	25,708	3.09
Indiana	6	16,378,580	29,212,000	1.78	16,806	6.51
Ohio	7	15,641,225	26,439,000	1.69	21,371	4.28
Virginia	8	11,900,933	20,375,000	1.71	12,312	4.28
Colorado	9	9,847,707	27,613,000	2.80	12,366	4.13
Wyoming	10	6,571,683	17,363,000	2.64	4,843	6.34
Tennessee	11	5,610,959	9,694,000	1.73	7,849	3.16
Utah	12	4,842,544	12,253,000	2.53	3,352	7.57
Missouri	13	3,732,421	9,637,000	2.58	5,964	3.47
Iowa	14	3,683,635	10,525,000	2.86	6,965	3.02
Total of U. S.		500,744,970	933,774,000	1.86	522,150	4.73

Coal is produced in 33 states, including Alaska, and it may be of interest to notice the production in the different geologic provinces into which these states are grouped. Figures are for 1928.

Province	*Tons*
Northern and Middle Appalachians (Pa., Ohio, Md., W. Va., eastern Ky., Va., Tenn.)	345,577,581
Southern Appalachians (Ala.)	17,621,362
Northern Interior (Mich.)	617,342
Eastern Interior (Ill., Ind., western Ky.)	88,603,995
Northern Western Interior (Iowa, Mo., Kan.)	10,225,780
Middle Western Interior (Ark., Okla.)	5,162,298
Southwestern Interior (Tex., bituminous)	117,849
Gulf Coast (Tex., lignite)	1,064,185
Northern Great Plains (N. Dak., lignite)	1,649,930
Rocky Mountains (Mont., Wyo., Colo., Utah, N. Mex.)	27,297,980
Pacific coast (Wash.)	2,519,901
Total for United States	500,744,970

GYPSUM

For a good many years the gypsum industry made consistent gains each year. But the current business—and mental—depression has naturally affected this industry and therefore the production both in Iowa and in the nation was less in 1928 than in either 1926 or 1927. Combined with the reductions in amounts was a price cutting war that resulted in a reduction in total value of sales.

It is worth while to take note of the variety of uses to which gypsum is being put—insulation; tile of various kinds, such as partition, to which it is very well adapted, roofing and special purposes; wall board and plaster board, which are being used in enormous amounts; and the various kinds of plasters. This great variety of uses is one of the factors that helps the industry keep active in periods of slow movement such as the present.

There were in Iowa seven active producers of gypsum and its

Gypsum Production in 1927 and 1928

	Iowa			
	1927		1928	
	tons	*value*	*tons*	*value*
Crude gypsum mined	792,159		764,044	
Sold crude—cement mills	138,375	$ 384,024	153,225	$ 239,227
agricultural	1,262	7,677	1,371	8,036
Total sold crude	139,637	391,701	154,596	247,263
Sold calcined—stucco	18,743	115,267		
neat and sanded plaster	379,702	2,711,701		
fibered plaster			253,114	1,197,374
sanded plaster			56,162	373,477
neat plaster			45,235	304,805
plaster of paris(a)	6,624	51,317	16,212	110,377
plaster and wall board	104,851	2,603,155	120,257(c)	2,471,806
partition tile	55,516	487,844	59,008	390,373
insulating, & c.(b)	18,869	352,512	15,152	259,739
Total sold calcined	584,305	6,321,796	565,140	5,107,951
Total sold	723,942	6,713,497	719,736	5,355,214
	United States			
Plants active	60		58	
Total mined	5,346,888		5,102,250	
Sold crude	965,371	$ 2,388,663	999,412	$ 1,902,034
Sold calcined	3,912,211	39,785,791	3,641,385	30,134,129
Total sales	4,877,582	42,174,454	4,640,797	32,036,163

(a) Includes: Sold to plate glass works, Keene's cement.
(b) Includes: Roofing tile, special tile, other building material.
(c) Equals 132,342,827 square feet, or 3,038 acres, 4.75 square miles.

products in 1928. One of these, the Hawkeye Gypsum Products Company of Fort Dodge, produces only crude gypsum. The six plants that calcine gypsum have 28 kettles with a daily capacity of 4,204 tons. The 51 plants in the United States have 182 kettles with a daily capacity of 22,350 tons and 15 rotary kilns with a capacity of 4,020 tons. This gives a total daily possible output of 26,370 tons.

LIMESTONE AND LIME

The stone industry in Iowa experienced a healthy growth in 1928, chiefly because of increase in the use of crushed rock for concrete and road metal and for agricultural purposes. This latter use is growing as farm lands are becoming impoverished and farmers are learning the advantages of liming their soils. The state's road building program likewise is helping the stone industry and doubtless will do so for many years to come now that everyone is learning to appreciate the benefits of better roads.

The following table shows the changes in output from the previous year. There are only two lime burning firms in the state, the Dubuque Stone Products Co., and the Hurst Estate, so the data regarding their product must be combined with those of other materials. Limestone was produced in forty-five states in 1928 and Iowa ranked fifteenth among these.

Production of Stone and Lime, 1927 and 1928

	1927		1928	
Kind	*tons*	*value*	*tons*	*value*
Building	3,160	$ 4,869	8,750	$ 13,000
Rubble			3,800	3,985
Riprap	124,400	123,321	106,790	87,586
Concrete and road metal	866,590	839,463	1,199,230	1,306,984
Ballast	105,140	93,773	112,040	109,160
Flux	9,550	12,146	6,840	9,767
Sugar fact., lime, etc.	5,536	38,392	10,417	28,736
Agriculture	163,680	156,069	207,660	180,770
	1,278,056	$ 1,267,033	1,666,270	$ 1,742,252
Stone in U. S.	99,662,270	112,439,824	96,864,650	110,231,974
Lime in U. S.	4,414,932	38,638,413	4,458,412	36,449,635

SAND AND GRAVEL

The production of sand increased in 1928 by 337,416 tons over that in 1927 and the value was $228,154 greater, a very gratifying increase. Production of building sand was 51,939 tons less, but the

Production of Limestone and Lime in Iowa in 1928

Counties	No. Producers	Building Stone, rubble, riprap(a)		Concrete, road metal (b)		Other uses (c)		Total	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Appanoose(1), Decatur(1), Van Buren(1)	3	(d)		10,800	$ 16,670	5,680	$ 8,345	16,480	$ 25,015
Black Hawk(2), Fayette(1)	3	....	....	195,422	194,937	(d)	....	195,422	194,937
Cerro Gordo(1), Mitchell(1) Winneshiek(2)	4	....	....	e	....	43,715	61,229	43,715	61,229
Clayton	3	(d)	....	77,014	65,479	....	....	77,014	65,479
Clinton(1), Jackson(1), Scott(2)	4	(d)	....	249,690	219,245	73,810	62,212	323,500	281,457
Dubuque	4	(d)	....	258,484	321,836	(d)	....	258,484	321,836
Hardin (1), Marshall (2), Pocahontas (1)	4	(d)	....	270,731	261,010	180,617	180,609	451,348	441,619
Johnson(1), Linn(2), Louisa(1)	4	....	....	183,900	229,190	(d)	....	183,900	229,190
Jones	3	14,474	$16,047	23,597	23,698	12,280	10,746	50,351	50,491
Lee	3	(d)	....	67,507	90,655	(d)	....	67,507	90,655
Total for 1928	35	119,340	104,571	1,199,230	1,306,984	336,957	328,433	1,667,721	1,761,908
Total for 1927	30	127,560	128,190	866,590	839,463	283,906	299,380	1,278,056	1,267,033

(a) Includes: Rough building stone, 3 operators, 8,750 tons or 110,000 cu. ft., value $13,000; rubble, 5 operators, 3,800 tons, value $3,985; riprap, 11 operators, 106,790 tons, value $87,586.
(b) Total crushed stone sold was 1,311,270 tons, value $1,416,144.
(c) Includes: Railroad ballast and flux, 4 producers, 118,880 tons, value $118,927; agricultural stone, 18 producers, 207,660 tons, value $180,770, sugar factories, lime, other uses, 5 producers, 10,417 tons, value $23,736.
(d) Included with Concrete.
(e) Included with Other Uses.

output of paving sand was 285,403 tons greater, a fact that sufficed to bring the totals well above those for the preceding year.

In the case of gravel the story was somewhat different. The output in 1928 was 894,940 tons less than during the preceding year, but owing to higher prices the value received was $27,625 greater in 1928 than in 1927. Because of the combination of these circumstances the total output of sand and gravel in 1928 was 557,524 tons less while its value was $255,779 more than that of the year before.

Among the counties Polk was the leader in sand production with Cerro Gordo a close second and Muscatine third. In values, however, Muscatine was the leader, with Cerro Gordo second, Linn third, Wapello fourth and Polk fifth. In gravel production Cerro Gordo was easily the leader, with Muscatine second, Polk third and Sac a close fourth. In values Muscatine was slightly ahead of Cerro Gordo, Polk was third and Sac was fourth. In combined output Cerro Gordo was leader, Muscatine second best, Polk third and Butler fourth. The values differed here as in the separate classes. Muscatine led, Cerro Gordo was slightly behind, Polk was third and Butler ranked fourth. Cerro Gordo's material was used chiefly for paving, Muscatine's was used mostly for paving, although a good deal was used in buildings.

Summary of Sand and Gravel Production, 1927 and 1928

Materials	1927			1928		
	No. pits	*tons*	*value*	No. pits	*tons*	*value*
Sand						
Molding	3	14,522	$ 11,231	5	64,929	$ 43,667
Building	45	583,339	268,056	38	531,400	280,843
Paving	29	802,974	292,504	38	1,088,377	450,712
Grinding, polishing		(a)		3	14,087	31,789
Engine	9	34,171	18,102	10	35,608	17,163
Filter	4	13,378	17,714	1	(a)	
R. R. ballast	6	30,226	11,292	3	10,660	3,060
Other	6	17,772	25,551	3	88,737	45,370
Total sand	56	1,496,382	644,450	60	1,833,798	872,604
Gravel						
Building	36	362,512	338,950	38	341,533	333,079
Paving	36	1,793,420	725,986	43	1,013,941	790,344
R. R. ballast	13	324,916	129,220	12	228,529	83,703
Other	3	3,913	570	5	5,818	15,225
Total gravel	55	2,484,761	1,194,726	64	1,589,821	1,222,351
Total output	71	3,981,143	1,839,176	80	3,423,619	2,094,955

(a) Included in Other Sand.

Polk's output was more evenly divided, with paving material preponderating, and Butler's output was nearly all paving and roadmaking sand and gravel.

The output during 1927 and 1928 is shown by products in the summary which follows and the production is given by counties, so far as it can be shown, in the more extended tables.

Production of sand in the United States was 93,588,339 tons, valued at $54,291,398 in 1927, and 97,737,717 tons, valued at $56,132,406 in 1928. Gravel output in 1927 was 103,865,930 tons, valued at $61,238,388, and in 1928 it was 111,381,151 tons, valued at $63,075,531. These figures made a total tonnage of 197,454,269 in 1927 and 209,118,868 in 1928, with values of $115,529,786 in the former year and $119,207,937 in the latter year.

Production of Sand and Gravel in 1928—Sand

Counties	Producers	Structural sand		Paving sand		Other sand *a*		Total sand	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Allamakee (1), Clayton (2), Fayette (1)	4	....	....	104,193	$ 65,022	(b)	....	104,193	$ 65,022
Appanoose (1), Louisa (0), Mahaska (1), Wapello (1)	3	87,399	$ 53,175	143,154	69,523	(b)	....	230,553	122,698
Black Hawk (2), Bremer (1), Tama (1)	4	56,064	37,895	(d)	....	55,772	$ 31,762	111,836	69,657
Boone (2), Dallas (0), Marshall (1), Story (0)	3	18,307	10,291	....	....	(c)	....	18,307	10,291
Buena Vista (0), Cherokee (1), Plymouth(1), Webster(1), Wright(0)	3	(b)	....	55,636	18,500	....	....	55,636	18,500
Butler (3), Floyd (1), Franklin (1), Mitchell (1)	6	9,985	4,970	100,551	38,453	(b)	....	110,536	43,423
Cerro Gordo	3	(b)	....	207,272	93,658	7,858	3,021	215,130	96,679
Clinton (2), Jackson (1)	3	11,914	8,484	29,237	16,156	....	....	41,151	24,640
Des Moines (1), Lee (2)	3	(b)	....	27,382	16,182	(b)	....	27,382	16,182
Dickinson(0), Lyon(1), Osceola(0)	1	(f)	....	....	....	....	....	(g)	
Dubuque (2), Scott (2)	4	36,000	27,025	64,394	17,896	....	....	100,394	44,921
Emmet (2), Humboldt (1) Palo Alto (1)	4	29,287	11,771	41,318	18,892	....	....	70,605	30,663
Johnson (1), Linn (2)	3	25,050	13,942	153,361	87,403	(b)	....	178,411	101,345
Muscatine	5	45,297	22,093	115,694	31,567	33,432	52,278	194,423	105,938
Polk	6	86,514	29,357	130,321	38,062	(b)	....	216,835	67,419
Sac	2	(e)	....	(e)		....	....	(g)	....
Sioux	3	(d)	....	(d)	....	89,635	35,025	89,635	35,025
Total	60	531,400	280,843	1,088,377	450,712	214,021	141,049	1,833,798	872,604
Totals for 1927	56	583,339	268,056	802,974	292,504	100,069	83,890	1,496,382	644,450

(a) Includes: Molding, cutting and grinding and blast, engine, filter, railroad ballast, and other sands.
(b) Included with paving sand.
(c) Included with structural sand.
(d) Included with other sand.
(e) Included with structural gravel.
(f) Included with paving gravel.
(g) Included with total sand and gravel.

Production of Sand and Gravel in 1928—Gravel

Counties	Producers	Structural gravel		Paving and other gravel (h)		Total sand and gravel		Total quantity washed	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Allamakee (1), Clayton (1), Fayette (1)	3	....	....	27,850	$ 20,275	132,043	$ 75,297	120,583	$ 68,397
Appanoose (0), Louisa (1), Mahaska (1), Wapello (1)	3	(f)	....	62,159	91,528	292,711	213,226	290,400	211,499
Black Hawk (2), Bremer (0) Tama (1)	3	11,082	$ 14,936	56,996	62,896	179,914	147,489	178,101	145,301
Boone (2), Dallas (1), Marshall (0), Story (1)	4	155,320	63,107	(e)	....	173,647	112,098	(i)	....
Buena Vista (1), Cherokee (1), Plymouth (1), Webster (1), Wright (1)	5	6,861	4,098	84,784	64,485	147,281	87,083	124,791	80,680
Butler (2), Floyd (0), Franklin (0), Mitchell (2)	4	(f)	....	128,344	107,732	238,880	151,155	208,281	148,149
Cerro Gordo	3	(f)	....	240,829	210,280	453,959	306,959	397,900	295,250
Clinton (3), Jackson (1)	4	35,603	29,475	79,500	54,591	156,254	108,706	130,854	84,968
Crawford (2), Harrison (1)	3	(f)	....	40,420	12,815	40,420	12,815	....	....
Des Moines (1), Lee (2)	3	(f)	....	12,800	14,675	40,182	30,857	(i)	....
Dickinson(1), Lyon (2), Osceola (1)	4	(f)	....	34,640	10,788	34,640	10,788	(i)	....
Dubuque (2), Scott (2)	4	21,220	8,920	23,185	15,648	144,799	69,493	108,800	54,525
Emmet (2), Humboldt (1) Palo Alto (2)	5	7,104	5,857	45,096	19,358	122,805	55,878	67,197	30,277
Johnson (1), Linn (0)	1	(c)	....	....	....	178,411	101,345	178,411	101,345
Muscatine	5	51,471	50,270	165,781	160,225	411,675	316,433	411,675	316,433
Polk	5	52,662	59,434	110,100	62,825	379,597	189,688	379,083	189,358
Sac	3	102,823	54,923	56,343	13,451	159,166	68,374	(i)	
Sioux	3	(f)	....	47,600	39,950	137,235	74,975	(i)	....
Undistributed		....	....	....	....	....	....	251,517	147,258
Total	64	341,533	333,079	1,248,288	889,272	3,423,619	2,094,955	2,847,553	1,873,539
Totals for 1927	55	362,512	338,950	2,122,249	855,776	3,981,143	1,839,176	2,419,280	1,340,037

(c) Included with structural sand.
(e) Included with structural gravel.
(f) Included with paving gravel.
(h) Includes: Paving and roadmaking, railroad ballast, other gravels.
(i) Included in undistributed.

MINERAL PRODUCTION IN 1929*

OUTLINE

The mineral industry showed slight gains in 1929, the improvements being in making of clay wares, in coal production and in the recovery of sand and gravel. Shipments of cement decreased somewhat and the value received was $953,679 less than during 1928. The gypsum industry also was unable to equal the level of production reached in 1928, even though that was lower than that of 1927. The production of stone and lime also was somewhat lower than in 1928. However, these items balanced each other sufficiently to make a slight increase in the total value of the output. The coal operators of the state are making a determined effort to win back the prestige and the markets lost to them during the strike of 1927 and the upward trend in the figures attests at least moderate success. Clay products also increased notably.

Value of mineral products the country over was 8 per cent greater than in 1928. The following figures summarize production during these two years.

	1928	1929
Metallic	$1,284,580,000	$1,475,900,000
Nonmetallic except fuels	1,206,158,000	1,141,000,000
Mineral fuels	2,884,962,000	3,202,000,000
Others	9,200,000	11,100,000
Total	$5,384,900,000	$5,830,000,000

* Statistics are collected by the U. S. Bureau of Mines, co-operating with the Iowa Geological Survey, except in the case of clay wares, which are gathered by the Bureau of the Census.

Mineral Production in Iowa in 1928 and 1929

Product	Unit	1928			1929		
		Producers	*quantity*	*value*	Producers	*quantity*	*value*
Cement........	bbl	6	6,880,731	$10,734,838	6	6,586,111	$9,781,159
Clay wares......		55		5,048,774	42		5,791,175
Coal...........	ton	222	3,683,635	10,525,000	201	4,241,069	11,948,000
Gypsum........	ton	7	719,736	5,355,214	8	670,203	4,668,856
Limestone and lime.........	ton	35	1,666,270	1,742,252	41	1,625,000	1,560,066
Sand and gravel.	ton	80	3,423,619	2,094,955	80	4,043,609	2,211,752
				$35,501,033			$35,961,008

CEMENT

Production of Cement in Iowa in 1928 and 1929

	1928	1929
Production, bbls.	7,070,172	6,373,330
Stock, Dec. 31, bbls.	1,559,925	1,347,144
Shipments, bbls.	6,880,731	6,586,111
Shipments, value	$10,734,838	$9,781,159
Average price per bbl.	$1.56	$1.49
Est. consumption, bbls.	5,348,807	5,462,534
Est. consumption per cap., bbls.	2.20	2.25
Surplus production, bbls.	1,531,924	1,123,577
Annual capacity, bbls.	9,593,000	9,592,900

The table given above shows that the cement industry experienced a slight decline during 1929 in practically all phases. Production was much less than in 1928, shipments were also less, and owing to lower factory prices the amount received was nearly a million dollars less in 1929. This, in face of the road building in progress, seems to indicate that other construction was slowing down, with resulting smaller demand for cement. That these conditions were prevalent the country over is suggested by the following data:

Production of Cement in the United States

	1928	1929
Production, bbls.	176,298,846	170,646,036
Shipments, bbls.	175,838,332	169,868,322
Shipments, value	$275,972,945	$252,153,789
Stocks, Dec. 31, bbls.	22,760,103	23,537,817
Plants active	156	163

In the district including eastern Missouri, Iowa, Minnesota and South Dakota, in which 12 plants were active each year, shipments amounted to 16,544,026 barrels, valued at $25,777,858, in 1928, and to 15,984,176 barrels, with a value of $23,430,891, in 1929.

The Pennsylvania-Dixie Cement Corporation bought the plant of the Pyramid Cement Company at Valley Junction April 1, 1928, and changed the name of the plant to its own a year later. The companies now operating in Iowa are the following:

Davenport, Dewey Portland Cement Co., Kansas City, Mo.
Brand—Dewey.
Des Moines, Hawkeye Portland Cement Co., Des Moines.
Brand—Hawkeye.
Gilmore City, Northwestern States Portland Cement Co., Mason City.
Brand—Northwestern.
Mason City, Lehigh Portland Cement Co., Allenton, Pa.
Brand—Lehigh.
Northwestern States Portland Cement Co., Mason City.
Brand—Northwestern.
Valley Junction, Pennsylvania-Dixie Cement Corporation, Des Moines.
Brand—Pyramid.

CLAY PRODUCTS

The Bureau of the Census has decided that it can not furnish the State Geological Surveys with any detailed statistics regarding production of clay wares in their states, or even any lists of producers. Therefore the only information that is so far available regarding production in 1929 is that given in the following brief summary, which as usual was supplied by the Bureau of the Census.

Number of establishments	42
Number of wage earners, average	1,670
Wages	$1,903,722
Cost of materials, fuel and purchased electric current	$1,516,737
Value of products	$5,791,175

As compared with a production in 1928 valued at $5,048,774 this summary shows a substantial gain in value of output. Nothing is known, however, as to the distribution of this increase among the different classes of ware. The Bureau of Mines reported 3,200 tons of raw clay sold at a value of $23,281. How much of this duplicates the figure given for the total output is not known.

Production of clay wares in the United States during the past two years was as follows:

Products	1928	1929
Common brick	$ 69,332,912	$ 60,181,451
Vitrified brick	7,800,090	7,281,681
Face brick	40,034,273	35,787,363
Other brick	1,506,077	1,711,052
Terra cotta	13,641,777	14,587,911
Hollow ware	25,791,634	30,121,712
Flue lining	2,693,098	2,482,141
Tile	31,523,096	22,009,133
Drain tile	5,256,220	6,542,821
Sewer pipe	23,968,773	21,421,897
Stove lining	343,907	468,248
Fire brick	37,391,735	42,699,145
Glass melting pots, etc.	1,993,609	2,276,009
Wall coping	663,131	486,664
Miscellaneous	3,830,181	4,609,180
Total	$265,770,513	$264,560,411
Pottery	107,780,369	
Grand total	373,550,882	
Clay sold	14,200,739	14,850,744

The following list of clay plant operators was furnished this Survey by the Bureau of Census before it decided not to furnish such lists.

Adel Clay Products Co., Adel, Dallas county.
Art Novelty Pottery Co., Waterloo, Black Hawk county.
Audubon Brick & Tile Works, Audubon, Audubon county.
Ballou Brick Co., Sergeant Bluff, Woodbury county; office 200 United Bank Bldg., Sioux City.
Bellevue Clay Products Co., Bellevue, Jackson county.
Centerville Clay Products Co., West Van Buren St., Centerville, Appanoose county.
Clermont Brick & Sand Co., Clermont, Fayette county.
Crystal Spring Clay Co., Kimballton, Audubon county.
Deep River Brick & Tile Co., Deep River, Poweshiek county.
Des Moines Clay Co., 908 Walnut St., Des Moines, Polk county.
Garrison Brick & Tile Works, Garrison, Benton county.
Gethmann Brick & Tile Co., Gladbrook, Tama county.
Gladbrook Pressed Brick Co., Gladbrook, Tama county.
Goldfield Clay Works, Goldfield, Wright county.
Goodwin Tile & Brick Co., S. E. 18th & Hartford Sts., Des Moines, Polk county; office 410 Shops Building.
Goss Brick Yard, N. Dodge Street, Iowa City, Johnson county.
Gould, G. O., Belle Plaine, Benton county.
Green Brick Co., 4200 Correctionville St., Sioux City, Woodbury county.
Hedrick Tile Works, Hedrick, Keokuk county.
Heim, John G., Brick Co., West 32d St., Dubuque, Dubuque county; office 2444 Broadway.
Iowa Pipe & Tile Co., Inc., E. 4th & Hayes Sts., Des Moines, Polk county.
Iowa Tile & Brick Co., Knoxville, Marion county.
Iowa Tile Works, Box 108, Davenport, Scott county.
Johnston Clay Works, Inc., First National Bank Bldg., Ft. Dodge, Webster county.
Kalo Brick & Tile Co., Snell Bldg., Ft. Dodge, Webster county.
Lehigh Sewer Pipe & Tile Co., Lehigh, Webster county; office 1526 Fifth Ave. North.
Lynnville Brick & Tile Works, Lynnville, Jasper county.
Mason City Brick & Tile Co., Inc., 19 W. State St., Mason City, Cerro Gordo county.
Maxwell Brick & Tile Co., Maxwell, Story county.
Meyer, Peter, New Sharon, Mahaska county.
Morey Clay Products Co., Ottumwa, Wapello county.

National Clay Products Co., 4th St. S. W., Mason City, Cerro Gordo county; office Box 424.
Nelson, John A., Clay Products Co., What Cheer, Keokuk county.
Nevada Brick & Tile Works, West Lincoln Way, Nevada, Story county; office Box 564.
North Iowa Brick & Tile Co., Inc., 19 West State St., Mason City, Cerro Gordo county.
Packwood Clay Tile Works, Packwood, Jefferson county.
Plymouth Clay Products Co., 20th St. & 15th Ave. South, Ft. Dodge, Webster county; office 1420 7th Ave. N., Ft. Dodge.
Postville Tile Works (Tuthill Bldg. Material Co.), Postville, Allamakee county: office 131 W. 63d St., Chicago, Illinois.
Redfield Brick & Tile Co., Inc., Redfield, Dallas county.
Reinbeck Pressed Brick Co., Reinbeck, Grundy county.
Rockford Brick & Tile Co., Rockford, Floyd county.
Roggentine Tile Factory, R. R. No. 4, Williamsburg, Iowa county.
Sheffield Brick & Tile Co., Sheffield, Franklin county.
Sioux City Brick & Tile Co., North Riverside St., Sioux City, Woodbury county; office 200 United Bank Bldg., Sioux City.
Standard Clay Products Co., Harvey, Marion county; office Third Ave. East, Oskaloosa, Mahaska county.
Standard Clay Products Co., Third Ave. East, Oskaloosa, Mahaska county.
Stockport Brick & Tile Co., Stockport, Van Buren county.
United Brick & Tile Co., Adel, Dallas county; office Lee Bldg., Kansas City, Mo.
United Brick & Tile Co., Plant No. 1, Boone, Boone county; office as above.
United Brick & Tile Co., Plant No. 33, Carlisle, Warren county; office as above.
United Brick & Tile Co., Plant No. 7, Creston, Union county; office as above.
United Brick & Tile Co., Plant No. 2, Des Moines, Polk county; office as above.
United Brick & Tile Co., Plant No. 5, Van Meter, Dallas county; office as above.
United Brick & Tile Co., Plant No. 3, Des Moines, Polk county; office as above.
United Brick & Tile Co., Plant No. 4, Des Moines, Polk county; office as above.
Vincent Clay Products Co., Inc., Ft. Dodge, Webster county; office 617 First Nat. Bank.
Washington Brick & Tile Works, Washington, Washington county.
What Cheer Clay Products Co., What Cheer, Keokuk county.
Wickham's Brick Yard, North 8th St., Council Bluffs, Pottawattamie county; office 19 Scott St.
Winfield Brick & Tile Co., Winfield, Henry county.

COAL

Comparison of the table that follows with the summary figures for 1928 will show that the Iowa coal industry made a long stride toward regaining the place it held a few years ago. Both tonnages and values increased largely, despite a slightly lower average price. This increase was reflected in the larger number of men who received employment and in the number of days they worked. They must not have worked quite so industriously, however, for the tonnage per man declined a little from its 1928 position.

Among the counties Marion retained leadership, although with a smaller output and a lessened margin. Polk, which had been second in 1928, dropped to third place in 1929, both because of slightly lower production and because of the larger output of Appanoose, which rose to second place. Polk, however, did retain second place in value received. Monroe advanced notably, in both absolute output and relative standing. A number of other counties also showed noteworthy improvement.

The following table is taken from the report of the Mine Inspectors for the biennial period ending December 31, 1929. It is of interest because it includes the smaller mines which do not report to the federal Bureau of Mines.

Counties	Mines		Tonnage		Employees	
	1928	1929	1928	1929	1928	1929
Adams	7	8	13,259	18,128	75	82
Appanoose	70	63	484,250	588,029	1,440	1,688
Boone	9	11	399,458	483,401	873	967
Dallas	4	4	273,470	419,397	593	668
Davis	2	2	3,220	2,917	13	13
Greene	3	3	4,918	7,069	19	23
Guthrie	7	6	8,901	9,409	51	50
Jasper	8	7	44,964	57,525	100	118
Jefferson	2	2	1,829	3,486	12	21
Lucas	5	8	327,447	442,471	408	634
Mahaska	30	30	58,678	56,741	176	204
Marion	25	33	858,634	795,671	965	1,057
Monroe	17	17	361,848	518,294	732	759
Page	5	4	20,560	20,236	82	90
Polk	19	20	591,752	569,681	953	898
Taylor	3	3	15,370	8,828	55	66
Van Buren	7	7	11,175	13,333	40	42
Wapello	29	27	87,184	103,814	240	251
Warren	6	8	163,290	202,063	288	375
Wayne	5	6	20,304	15,370	70	89
Webster	4	2	9,036	1,150	29	8
Totals	267	271	3,759,545	4,337,013	7,214	8,103
Local mines	214	217	697,829	738,528	2,052	2,266
Shipping mines	60	54	3,061,716	3,598,485	5,162	5,837
Mining machines	80	103				
Horses and mules	572	607				

Final figures of production in the United States during 1929 indicate that the tonnage of anthracite recovered was 73,828,195, with a value of $385,643,000. Tonnage of bituminous was 534,988,593, valued at $952,781,000. Total amount was 608,816,788 tons, valued at $1,338,424,000.

*Production, Value, Men Employed, Days Worked, and Output per Man per Day at Coal Mines in Iowa in 1929**
(Exclusive of product of wagon mines producing less than 1,000 tons)

County	Producers	Net tons				Value		Number of employees					Average number of days worked	Average tons per man per day
		Loaded at mines for shipment	Sold to local trade and used by employees	Used at mines for power and heat	Total quantity	Total	Average per ton	Underground			Surface	Total		
								Miners, loaders, and shot firers	Haulage and track	All others				
Adams	5	....	11,332	1,800	13,132	$ 40,000	$ 3.05	25	3	2	4	34	189	2.04
Appanoose	51	492,370	75,584	1,360	569,314	1,542,000	2.71	1,189	116	92	128	1,525	151	2.47
Boone	7	407,395	72,088	4,107	483,590	1,479,000	3.06	688	72	89	48	897	206	2.61
Dallas	4	404,498	13,260	1,638	419,396	1,170,000	2.79	433	49	55	37	574	206	3.55
Greene and Webster	4	....	3,777	....	3,777	15,000	3.97	15	2	2	3	22	71	2.42
Guthrie	6	....	10,609	....	10,609	42,000	3.96	30	2	4	4	40	154	1.72
Jasper	6	....	54,122	4,505	58,627	165,000	2.81	77	10	11	18	116	151	3.36
Jefferson	3	....	3,676	....	3,676	9,000	2.45	10	1	1	1	13	158	1.79
Lucas	4	425,592	4,543	9,902	440,037	1,324,000	3.01	400	71	105	42	618	197	3.61
Mahaska	25	....	48,616	139	48,755	126,000	2.58	120	4	6	9	139	148	2.37
Marion	17	709,563	54,109	16,995	780,667	2,255,000	2.89	694	97	124	53	968	229	3.53
Monroe	10	483,926	25,926	3,167	513,019	1,251,000	2.44	546	69	51	54	720	229	3.11
Polk	14	269,259	282,075	9,116	560,450	1,596,000	2.85	639	102	69	68	878	222	2.87
Taylor	3	358	8,470	....	8,828	36,000	4.08	34	4	2	2	42	120	1.75
Van Buren	4	3,619	6,103	75	9,797	27,000	2.76	18	2	1	2	23	168	2.53
Wapello	20	158	77,021	235	77,414	215,000	2.78	137	11	10	16	174	138	3.22
Warren	6	184,888	13,594	4,200	202,682	519,000	2.56	270	29	56	35	390	219	2.37
Wayne	5	2,175	13,095	....	15,270	48,000	3.14	53	5	7	8	73	114	1.83
Other counties (Davis, Keokuk, and Page)	6	....	22,029	....	22,029	89,000	4.04	30	6	6	7	49	133	3.38
Totals for 1929	201	3,383,801	800,029	57,239	4,241,069	11,948,000	2.82	5,408	655	693	539	7,295	195	2.98
Totals for 1928	222	2,849,348	781,390	52,897	3,683,635	10,525,000	2.86	5,055	766	644	500	6,965	175	3.02

* The figures relate only to active mines of commercial size that produced coal in 1929. The number of such mines in Iowa was 201 in 1929; 222 in 1928; and 183 in 1927.

Methods of mining in 1929: The tonnage by hand was 489,369; shot off the solid, 2,416,232; cut by machines, 1,282,612; not specified, 52,856.

Size classes of commercial mines in 1929: There were 5 mines in Class 1 B (200,000 to 500,000 tons) producing 32.6 per cent of the tonnage; 7 in Class 2 (100,000 to 200,000 tons) with 24.0 per cent; 8 in Class 3 (50,000 to 100,000 tons) with 14.7 per cent; 34 in Class 4 (10,000 to 50,000 tons) with 20.3 per cent; 147 in Class 5 (less than 10,000 tons) producing 8.4 per cent.

The following firms produced coal during 1928 and 1929.

Adams County
- Aukeny Coal Co., Villisca
- Black Diamond Coal Co., Route 1, Nodaway
- John G. Henton, R. F. D. 1, Carbon
- Larson & Turner, Route 6, Corning
- McKee Coal Co., R. 6, Carbon
- J. F. Ruth & Son, Carbon
- Smith Coal Co., Carbon
- Wild Coal Co., Carbon

Appanoose County
- Appanoose County Coal Co., Centerville
- Armstrong Coal Co., Cincinnati: office Commerce Bldg., Kansas City, Mo.
- Battle Creek Coal Co., Route 2, Mystic
- Big Slope Coal Co., Route 3, Centerville
- Bradshaw Coal Co., Dean
- Buban Coal Co., Route 1, Mystic
- Byte Coal Co., Route 3, Centerville
- Caldwell Coal Co., Exline
- Center Coal Co., Centerville
- Centerville Block Coal Co., Centerville
- Centerville Coal Co., Centerville
- Citizens Coal Co., Centerville
- Clarke Coal Co., Centerville
- J. A. Colgan Coal Co., Mystic
- Columbus Coal Co., Centerville
- Commercial Coal Co., Mystic
- Diamond Lump Coal Co., Centerville
- Domestic Coal Co., Cincinnati
- Duff Coal Co., Mystic
- Empire Coal Co., Centerville
- Enterprise Coal Co., Numa
- Fairlawn Coal Co., Centerville
- Friendship Coal Co., Cincinnati
- Garfield Coal Co., Centerville
  W. M. Evans, Tr. in Bankruptcy
- Guinn Coal Co., Coal City
- Hafner Coal Co., Cincinnati
- Happy Hollow Coal Co., Route 2, Cincinnati
- Helman Bros. Coal Co., Centerville
- Herr Coal Co., Plano
- Hi-Test Coal Co., Mystic
- Iowa Block Coal Co., Centerville
- Jerome Coal Co., Jerome
- Kincaide Coal Co., Centerville
- J. A. Koontz, Centerville
- Liberty Coal Co., Mystic
- Little Walnut Coal Co., Mystic
- W. W. Lowe, Brazil
- Maddalozzi Coal Co., Mystic
- McConville Coal Co., Centerville
- Monitor Coal Co., Centerville
- New Barrett Coal Co., Mystic
- New Egypt Coal Co., Mystic
- New Rock Valley Coal Co., Centerville
- New Star Coal Co., Route 1, Centerville
- North Hill Coal Co., Centerville
- Numa Coal Co., Numa
- Old King Coal Co., Centerville
- Peacock Coal Co., Brazil
- Prospect Coal Mine, J. F. Daniels, Exline
- Rathbun Coal Co., Rathbun
- Red Bird Coal Co., Seymour
- Rock Valley Coal Co., Centerville
- J. Rosenbaum & Son, Centerville
- Simatovich Coal Co., Dan Simatovich, Route 3, Centerville
- Star Coal Co., Mystic
- Sunshine Coal Co., Centerville
- Thistle Coal Co., Cincinnati
- J. A. Truby, Route 1, Mystic
- Walnut Creek Coal Co., Jerome
- Water Lily Coal Co., V. Blazina & Son, Rathbun
- White Oak Coal Co., Exline

Boone County
- Benson Coal Co., Boone
- Boone Coal Co., Inc., Boone
- Fort Dodge, Des Moines & Southern R. R. Co., Ogden
- Kennedy & Blosser, Ogden
- Kristianson Bros., Route No. 1, Ogden
- Scandia Coal Co., Madrid: office 606 Grand Ave., Des Moines
- Spring Valley Coal Co., Boone

Dallas County
- Dallas Fuel Co., Granger: office Insurance Exchange Bldg., Des Moines
- Norwood-White Coal Co., Moran: office 907 Bankers' Trust Bldg., Des Moines
- Scandia Coal Co., Des Moines
- Shuler Coal Co., Waukee: office So. Surety Building, Des Moines

Davis County
- Henderson & Goodwin Coal Co., Floris
- Lunsford Bros. Coal Co., Bloomfield
- Mitchell Bros. Coal Co., R. F. D. No. 2, Floris
- Van Patten Coal Co., Floris

Greene County
- Creek Side Coal Co., Dawson
- Harold McElheny Co., Rippey
- Riverside Coal Co., Rippey

Guthrie County
- Butler Coal Co., Guthrie Center
- Mallon Coal Co., Guthrie Center
- John Mansell Coal Co., Guthrie Center
- Elmer Renslow Coal Co., Guthrie Center
- W. H. Scott, R. R. No. 5, Guthrie Center

H. M. Sipe Coal Co., Guthrie Center
Thomas Coal Co., Guthrie Center

Jasper County

Colfax Coal Co., Colfax
Hopkins Coal Co., Colfax
Jackson Coal Co., R. F. D. 4, Newton
Marshall Coal Co., Monroe
McKeevers Coal Co., Colfax
McSeel Coal Co., Colfax
Newton Coal Co., Newton
Merl Stines, R. F. D. No. 3, Monroe

Jefferson County

Bonnett Coal Co., Fairfield
R. B. Cross, R. 2, Birmingham
Star Coal Co., R. F. D. 7, Fairfield

Keokuk County

Carson Bros., What Cheer
Clive Coal Co., Delta

Lucas County

Cedar Coal Co., Route 4, Melrose
Central Iowa Fuel Co., Williamson: office 1209 So. Surety Bldg., Des Moines
Consolidated Indiana Coal Co., Melcher: office 139 West Van Buren St., Chicago, Ill.
Mederais Coal Co., R. 1, Lacona
Union Coal Co., John T. Griffith, Box 131, Lucas

Mahaska County

Charles Ahrweiler, Oskaloosa
Ball & Co., What Cheer
Blomgren Bros. Coal Co., R. F. D., Lovilia
Cromwell & Wilson, Givin
De Frehn & Son, Oskaloosa
Eddy Coal Co., Beacon
Edwards Bros. Coal Co., Oskaloosa
A. M. Ellis Coal Co., Givin
Evans Bros. Coal Co., Eddyville
Evans Coal Co., Evans
Fedro Coal Co., R. F. D., Givin
Steve & Joe Gasper, Truax
Givin Coal Co., Givin
G. A. Hausel Coal Co., Rose Hill
Hynick Coal Co., R. R. 1, Givin
Thomas Lewis, Givin
Mathes Coal Co., Givin
Mitchell Coal Co., 902 1st Ave. W., Oskaloosa
J. M. Mitrisin, Oskaloosa
O'Brien & Edwards, Beacon
Oskaloosa Coal Co., Oskaloosa
Owens & Griffith, Beacon
Henry Pool, Oskaloosa
Roberts Bros. Coal Co., Oskaloosa
Swanson & Hohn Coal Co., Oskaloosa
Sweitzer Coal Co., Eddyville
Thatcher Coal Co., Oskaloosa
White & Ferguson, Rose Hill
Williams Coal Co., New Sharon
Woodward & Boggs Coal Co., Oskaloosa

Marion County

Bishop Coal Co., R. F. D., Knoxville
Bradley Bros. Coal Co., R. 1, Knoxville
Cedar Creek Coal Co., Bussey
Consolidated Indiana Coal Co., Melcher: office 139 West Van Buren St., Chicago, Ill.
Cox Bros., R. 3, Knoxville
Charles Fortner Coal Co., R. F. D., Knoxville
Hamilton Coal Co., Hamilton
Hayes Bros. Coal Co., Knoxville
Horse Shoe Coal Co., Dupont & Villont, Bussey
Roy Hudson Coal Co., R. 8, Knoxville
Johns Bros. Coal Co., Bussey
C. C. Kendall Coal Co., Marysville
Arthur Lockhart Coal Co., R. F. D., Oskaloosa
Mayer Coal Co., Harvey
McAllister & Gilcrest, Dallas
Walter McElrea, Dallas
Pershing Coal Co., Pershing: office 648, Ins. Exch. Bldg., Des Moines
John Miller & Sons, Pleasantville
W. L. Nail Coal Co., Knoxville
J. W. Newton, Dallas
Riggens Coal Co., Harvey
Red Rock Coal Co., Melcher: office 1219 So. Surety Bldg., Des Moines
Ben Rowley, Knoxville
Success Coal Co., Otley
Swan Coal Co., Swan
Vanceunebrak Bros. Coal Co., Knoxville

Monroe County

Blackstone Coal Co., R. F. D. 1, Lovilia
Carbon Coal Co., Albia
City Coal Co., Albia
De Ross Coal Co., Route 3, Albia
Federal Coal Co., Route 3, Albia
Graham Coal Co., Avery
Hocking Coal Co., Hocking
Independent Coal Co., J. H. Homerin, Albia
Lovilia Coal Co., Lovilia
Monroe Block Coal Co., Albia
Oak Block Coal Co., W. J. Gragg, R. 6, Albia
Plainview Coal Co., Albia
Rex Fuel Co., Albia
Smoky Hollow Coal Co., Albia

Page County

Clarinda Coal Co., Clarinda
Evans Coal Co., Clarinda
Pearson Coal Co., Clarinda
Sawmill Coal Co., Clarinda

Polk County
- Adelphi Coal & Mining Co., Adelphi: office 2300 East 24th St., Des Moines
- Beck Coal & Mining Co., Des Moines
- Bennett Bros. Coal Co., Des Moines
- Carbon Mining Co., 907 Bankers Trust Bldg., Des Moines
- Clover Leaf Coal Co., Des Moines
- Commerce Coal Co., Commerce
- Des Moines Coal Co., Valley Nat'l Bank Bldg., Des Moines
- Des Moines Ice & Fuel Co., Des Moines
- Economy Coal Co., Des Moines
- Gibson Coal Co., Rider: office 225 Iowa Bldg., Des Moines
- Independent Coal Co., Des Moines
- Norwood-White Coal Co., Herrold: office, Des Moines
- Preston Coal Co., Carlisle
- Spring Valley Coal Co., Boone
- Standard Coal Co., 2456 East Grand Ave., Des Moines
- Robert Stanford Coal Co., Des Moines
- Urbandale Coal Co., Des Moines

Taylor County
- Bean Coal Co., New Market
- Carbon Coal Co., S. Osborn, New Market
- New Market Coal Co., New Market
- Richardson Coal Co., Gravity

Van Buren County
- Blue Jacket Coal Co., Clark Bourland, Farmington
- A. Carmichael, Birmingham
- J. Daniels & Sons, Douds
- Greer & Sons Coal Co., Mt. Zion
- Ratcliff Coal Co., Douds

Wapello County
- Airline Coal Co., 415 S. Willard St., Ottumwa
- Best Coal Co., William Rogers, R. F. D., Ottumwa
- Big Four Coal Co., Ottumwa
- Blakesburg Coal Co., Ottumwa
- Carr Brothers Coal Co., Eldon
- J. W. Dawson, Kirksville
- Gibbs Bros. Coal Co., R. F. D., Ottumwa
- Glendale Coal Co., 1317 Castle St., Ottumwa
- Happy Hollow Coal Co., R. F. D., Ottumwa
- Hartwig Bros. Coal Co., Eldon
- Indian Head Coal Co., Ottumwa
- L. A. Keller Coal Co., R. F. D. 5, Ottumwa
- Kirkville Coal Co., Lipovac & Hoover, Ottumwa
- Lafayette Coal Co., 1024 West 2d St., Ottumwa
- Larkin Coal Co., R. F. D. 4, Ottumwa
- Miers & Houk Coal Co., R. F. D. 8, Ottumwa
- Munterville Coal Co., Blakesburg
- Henry Rowley, R. 3, Blakesburg
- Santen Coal Co., R. F. D. 3, Blakesburg
- Sickles Coal Co., Eldon
- Simpson Bros. & Howard, Ottumwa
- Stribling Coal Co., Eldon
- Thode Coal Co., R. F. D., Blakesburg
- Union Coal Co., Ottumwa
- Utterback Coal Co., R. F. D. 8, Ottumwa
- Wapello Coal Co., Ottumwa
- Weist Coal Co., Eldon

Warren County
- Roy Carpenter, Lacona
- Great Western Coal Co., Orillia: office Polk Bldg., Des Moines
- Indian Valley Gloss Coal Co., Hartford: office Ins. Exch. Bldg., Des Moines
- Lanti Miller Coal Co., Lacona
- Oak Hill Coal Co., Carlisle
- Ridge Block Coal Co., Carlisle
- Scotch Ridge Coal Co., R. F. D., Carlisle

Wayne County
- L. E. Bennett, R. 2, Promise City
- Hayhurst Coal Co., R. 2, Promise City
- Rissler & Yocum, Promise City
- Violet Valley Coal Co., Seymour
- Whalen Coal Co., Seymour

Webster County
- A. Munson Coal Co., Lehigh

GYPSUM

The mining of crude gypsum and the sales of crushed unburned gypsum both were less in 1929 than in 1928, and the output of calcined and processed gypsum was somewhat less also. More fibered plaster and boards were sold, but in the case of the latter the price received was less. Some of the apparent discrepancies in figures for the past three years are no doubt due to differences in classification.

Iowa operated 27 kettles in 1929 as against 28 in 1928, but the total capacity is given as 4,444 tons compared with 4,204 tons the year before.

Producers in recent years were these:

Federal Gypsum Co., Centerville (Now U. S. Gypsum Co.).
Certainteed Products Corp., Fort Dodge. Office 100 E. 42d St., New York.
Universal Gypsum & Lime Co., Fort Dodge. Offices 1535 Conway Bldg., Chicago.
United States Gypsum Co., Fort Dodge. Offices 300 W. Adams St., Chicago.
Hawkeye Gypsum Products Co., Fort Dodge.
Johnson Clay Works, 214 First Nat. Bank Bldg., Fort Dodge.
Wasem Plaster Co., Warden Apts., Fort Dodge.
Cardiff Gypsum Plaster Co., 903 Central Ave., Fort Dodge.

Production of Gypsum in 1928 and 1929

	1928		1929	
	tons	*value*	*tons*	*value*
Crude gypsum mined	764,044		718,503	
Sold crude—cement mills	153,225	$ 239,227	147,330	$ 232,846
Agriculture	1,371	8,036	1,112	5,888
Total sold crude	154,596	247,263	148,442	238,734
Sold calcined—neat and sanded plaster	101,397	678,282	39,114	208,416
Fibered plaster	253,114	1,197,374	276,033	1,276,645
Plaster board and wall board	120,257 (c)	2,471,806	126,018 (c)	2,240,024
Partition tile	59,008	390,373	54,468	356,160
Other building(a)	15,152	259,739	17,173	274,823
Plaster of paris(b)	16,212	110,377	8,955	74,054
Total sold calcined	565,140	5,107,951	521,761	4,430,122
Total sold	719,736	5,355,214	670 203	4,668,856

(a) Includes: Roofing tile, special tile, insulating, fireproofing, other building material.
(b) Includes: Keene's cement, sold to plate glass works.
(c) 1928: Equals 132,342,827 square feet, or 3,038 acres, or 4.75 square miles. 1929: 151,961,741 square feet, or 3,489 acres, or 5.45 square miles.

The table following shows that production in the United States dropped a little from that of 1928, although the amount sold crude was somewhat larger. Amounts and values of neat and sanded plaster were considerably less, but amounts and values of boards and lath were notably larger.

Production of Gypsum in the United States in 1929

	Plants	Mined	Sold Crude		Sold Calcined		Total Value
		tons	*tons*	*value*	*tons*	*value*	
Iowa.........	8	718,503	148,442	$ 238,734	521,761	$ 4,430,122	$ 4,668,856
Michigan.....	5	898,547	213,657	299,249	481,872	4,016,085	4,315,334
Nevada......	5	225,514	43,815	131,735	148,640	1,159,119	1,290,854
New York....	11	1,284,338	298,793	707,644	859,147	7,632,208	8,339,852
Ohio.........	3	374,008	12,190	30,696	356,734	3,270,744	3,301,440
Oklahoma....	3	369,433	b		b		2,255,874
Texas........	4	520,519	29,991	47,836	416,276	3,392,451	3,440,287
Others(a).....	20	625,270	318,809	640,885	577,150	5,295,461	3,680,972
Total......	59	5,016,132	1,065,697	2,096,779	3,361,580	29,196,190	31,292,969
1928.........	58	5,102,250	999,412	1,902,034	3,641,385	30,134,129	32,036,163

(a) Includes: Arizona, California, Colorado, Kansas, Montana, New Mexico, South Dakota, Utah, Virginia, Wyoming.
(b) Included in Others.

An interesting development of the year was the discovery by the Bureau of Mines that anhydrite in very fine form dissolves in water about as fast as gypsum. Hence in this condition it can be used as retarder in cement. (Pit and Quarry, Jan. 1, 1930.) White cements of excellent cementing powers have been made from anhydrite also. (Rock Products, vol. 33, Jan. 4, 1930, p. 111.) Flexible wall board and lath have been perfected recently and several other new products have been made public.

LIMESTONE AND LIME

The tables which follow show a slight reduction in the amount of stone marketed in 1929 and a somewhat greater reduction in its value as compared with that produced in 1928. This lessened output was shared by every important branch of the industry, even the classes of crushed stone—for concrete, ballast, agriculture, etc.—being produced in lessened amounts. And these are much the most important elements in Iowa's stone trade. Other construction materials—rough stone for building and riprap for river improvement and similar projects—stand next in order of value.

Only one lime plant was operated, that of the Hurst estate at Hurstville. The Dubuque Stone Products Co. dismantled its kilns in December, 1928, thus terminating an operation of many years standing.

Scott was the leading county during this year with Marshall, Madison, Hardin, Black Hawk, and Johnson following in order among the leaders. Among individual producers the Linwood Cement Co. of Scott county was the foremost, while the River Products Co. of Johnson county stood next. This of course does not include the materials extracted by the cement companies for their own manufacturing purposes.

Production of Stone and Lime, 1928 and 1929

Kind	1928			1929		
	Plants	*tons*	*value*	Plants	*tons*	*value*
Building	3	8,750	$ 13,000	3	12,510	$ 13,839
Rubble	5	3,800	3,985	3	2,110	2,952
Riprap	11	106,790	87,586	12	92,660	103,777
Concrete & road metal	25	1,199,230	1,306,984	29	1,158,490	1,182,773
Railroad ballast	3	112,040	109,160	5	107,390	45,809
Flux	2	6,840	9,767	2	10,160	17,923
Agriculture	18	207,660	180,770	19	193,050	159,752
Sugar factories, etc.	5	10,417	28,736	4	48,630	28,168
	35	1,666.270	1,742.252	41	1,625.000	1,560,066

Iowa ranked seventeenth among the states in the production of limestone in 1929. Pennsylvania was the leader, followed closely by Ohio, Michigan and New York. In values, however, Indiana was far and away the leader, on account of its output of high grade building stones from the Bedford quarries. Output from some of the important states was as follows:

State	*Tons*	*Value*
Pennsylvania	14,525,080	$ 14,024,287
Ohio	14,241,690	11,789,747
Michigan	13,572,010	8,425,261
New York	11,105,850	13,841,827
Illinois	8,345,080	6,965,264
Indiana	5,129,220	22,191,883
Missouri	4,093,430	5,704,241
Wisconsin	3,441,070	3,882,645
West Virginia	3,301,160	2,978,873
Texas	3,238,760	2,390,235
Total for U. S.	100,686,960	$113,906,071

The total amount of stone of all kinds produced in the United States during this year was 141,109,580 tons with a value of $202,692,-

762. The amount of lime sold from the 400 producing plants was 4,260,000 tons, valued at $33,387,000. Pennsylvania was leader also in total quantity of stone produced, with Ohio second here also, but again Indiana was leader in values, with Pennsylvania second and New York third. Ohio was leader in lime burning and Pennsylvania was second.

The following is a list of limestone producers in Iowa:

Allamakee County
- Holtzhammer & Kaiser, La Crosse, Wis. Quarry at Heitman
- Thomas Eagon, La Crosse, Wis. Quarry at Lansing
- City of Lansing, Lansing
- Allamakee County, Highway Dept., Waukon

Appanoose County
- Wm. B. Swan, Plano

Black Hawk County
- The Builders Material Co., Cedar Rapids. Brandon (Hawkeye Quarry)
- A. Bartlett, 1165 E. Fourth St., Waterloo
- Waterloo Dredging Co., W. Mullan Ave., Waterloo

Bremer County
- Waverly Stone & Gravel Co., Fowler Bldg., Waterloo. Quarry at Waverly

Butler County
- Concrete Materials Corp., Waterloo. Quarry at Clarksville
- Chicago, Rock Island & Pacific Ry. Co., La Salle Street Station, Chicago, Ill. Quarry at Clarksville

Cerro Gordo County
- Henry Kuppinger, Mason City
- Stoddard Stone Products Co., J. C. Stoddard, Mason City
- N. W. States Portland Cement Co., Mason City
- Quimby Stone Co., C. K. Quimby, 24 13th St., N. E., Mason City

Clayton County
- H. D. Kregel Estate, Garnavillo
- Western Quarry Co., 1422 Walnut St., Des Moines
- E. C. Schroeder & Co., McGregor
- U. S. Engineer Office, Box J. Commercial Sta., St. Paul Minn. Quarry at McGregor

Clinton County
- C. T. Hanrahan, Charlotte
- Arthur Daniels, Lost Nation
- N. A. Gaarde, Clinton
- Lee Bloore, 1619 N. 4th St., Clinton
- George T. Smith, 700 S. Bluff Blvd., Clinton

Dallas County
- Chicago, Rock Island & Pacific Ry. Co., La Salle Street Station, Chicago, Ill. Quarry at Van Meter

Decatur County
- Davis City Quarry Co., Davis City

Des Moines County
- Limestone Fertilizer Co., Whitaker Bldg., Davenport. Quarry near Oakland, Louisa Co.

Dubuque County
- Wm. Becker, 1333 Kaufman Ave., Dubuque
- Ludwig Grassel, Dubuque
- Dubuque Stone Products Co., Dubuque
- Okey & Fager, Cassville, Wis. Quarry at Dubuque
- B. N. Arquitt, Farley
- Dubuque County, Highway Dept., Dubuque. Quarry at Waupeton

Fayette County
- M. O. Weaver, Iowa Falls. Quarry at Fayette
- Weaver Construction Co., Fayette
- Graham & Schenk Co., West Union

Floyd County
- H. L. Winskeel, Benton, Wis. Quarry at Lithograph City (Orchard)
- Henry Gaythre, R. D. 6, Charles City

Hardin County
- Iowa Limestone Co., 907 Bankers Trust Bldg., Des Moines. Quarry at Alden

Henry County
- J. F. Lynn, 120 S. La Salle St., Chicago, Ill. Quarry at Mount Pleasant

Howard County
- Cresco Stone & Concrete Co., Cresco

Jackson County
- Isaac Voelpell, Baldwin
- Clarence C. Putman, Bellevue
- A. A. Hurst, Maquoketa. Quarry at Hurstville (near Maquoketa)

Johnson County
- River Products Co., 20-21 Schneider Bldg., Iowa City. Quarry at Coralville (Conklin Quarry)

Jones County
- Men's Reformatory, Anamosa

Production of Limestone and Lime in Iowa in 1929

Counties	Plants	Building stone, rubble, riprap		Concrete, road metal		Other uses(a)		Total	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Allamakee(1), Fayette(1), Winneshiek(1)	3	....	....	46,830	$ 56,560	(b)	....	46,830	$ 56,560
Black Hawk(2), Butler(1)	3	....	....	165,560	146,936	(b)	....	165,560	146,936
Cerro Gordo(2), Floyd(1) Howard (1), Mitchell (1)	5	....	....	57,554	38,625	15,608	$ 20,445	73,162	59,070
Clayton	3	....	....	70,800	74,250	....	....	70,800	74,250
Clinton (2), Jackson (3)	5	58,550	$ 60,550	5,700	7,448	4,000	9,025	68,250	77,013
Dallas (1), Madison (1), Pocahontas (1)	3	....	....	161,466	146,980	4,116	3,104	165,582	150,084
Dubuque	4	(b)	....	144,847	162,656	(b)	....	144,847	162,656
Hardin (1), Marshall (2)	3	(b)	....	201,308	195,907	115,372	81,692	316,680	277,599
Johnson (1), Jones (2)	3	10,215	11,015	130,265	149,849	17,409	16,779	157,889	177,643
Lee (2), Van Buren (3)	5	17,593	24,467	49,234	70,992	40,656	10,715	107,483	106,174
Linn (1), Muscatine (1) Scott (2)	4	(b)	....	214,287	205,027	93,622	62,681	307,909	267,708
Totals	41	107,280	120,568	1,158,490	1,182,773	359,230	251,652	1,625,000	1,560,066
Totals for 1928	35	119,340	104,571	1,199,230	1,306,984	336,957	328,433	1,667,721	1,761,908

(a) Includes: Railroad ballast, flux, sold to sugar factories, agricultural limestone, railroad fills, lime.
(b) Included in Concrete.

Columbia Quarry, Geo. B. Shaler & G. J. Albright, Cedar Rapids. Quarry at Stone City
H. Dearborn Sons, Stone City
Jno. Ronen, Estate, Anamosa Quarries, Stone City

Lee County
McManus Quarries Co., Inc., 112 Masonic Bldg., Keokuk. Quarry at Ballinger Station
Keokuk Quarry & Constr. Co., Frank L. Griffey, 1325 Main St., Keokuk

Linn County
Builders' Material Co., Cedar Rapids
Falcon & Reinking, Inc., Box 761, Cedar Rapids. Quarries at Adair and Cedar Rapids.
Jos. Verba, Mt. Vernon

Louisa County
County Engineer, Loulsa County, Wapello

Madison County
Hawkeye Portland Cement Co., 802 Hubbell Bldg., Des Moines. Quarry at Earlham

Marshall County
Chicago & North Western Ry. Co, 400 W. Madison St., Chicago, Ill. Quarry at Le Grand
Le Grand Lime Stone Co., Le Grand (Main office, 29 S. La Salle St., Chicago, Ill.)
Marshall County, County Engineer, Marshalltown

Mitchell County
Plim Dykeman, Orchard
F. L. Belzer, Osage
H. L. Wilson, Osage

Pocahontas County
N. W. States Portland Cement Co., Gilmore Portland Cement Corp., Mason City. Quarry at Gilmore

Scott County
Dolese Bros. Co., 205 W. Wacker Drive, Chicago, Ill. Quarry at Buffalo
Linwood Cement Co., 713 Kahl Bldg., Davenport. Quarry at Linwood
Herman Witt, R. D. 1, McCausland. Quarry at Gambril

Van Buren County
Des Moines Valley Stone Co., Bonaparte
Douds Stone Co., H. E. Millen, Secy., Douds
W. H. Swank, Fairfield. Quarry at Farmington

Winneshiek County
Hallett Construction Co., Crosby, Minn. Quarry at Decorah (1½ mi. from—on farm of Ed Yeoman)
Decorah Stone Products Co., Decorah
M. O. Weaver, Webster City. Quarry at Decorah
State of Iowa, Highway Dept., Ames

SAND AND GRAVEL

The two main features in the sand and gravel industry during 1929 were the downward trend in the output and sale of structural materials in both classes and the upward trend in the use of these materials for paving and other road-making purposes. Naturally these trends reflect conditions in these industries—building was slowing down, paving was speeding up. Other changes are noticeable, but are of much less importance. Iowa's sands and gravels are of such nature that they will always find their chief uses in these rougher phases of construction and industry.

Another notable feature of this as of other years is the fluctuations in county productions. Certain counties which show a high production in one year may show little or none in the succeeding year. This again reflects local construction conditions, as these materials are normally transported only short distances. When building or road making is active in a locality production of construction materials will flourish. When work slackens output decreases.

Muscatine was the leading county in tonnage with Cerro Gordo, Butler, Sac, Polk and Mahaska following in that order. In values Muscatine led and Cerro Gordo, Sac, Mahaska, Polk and Butler were next in order. The Concrete Materials Corporation of Waterloo, with pits in several counties, was the largest producer, the Ideal Sand and Gravel Co. of Mason City was second, and the Automatic Gravel Products Co. of Muscatine was third.

Summary of Sand and Gravel Production, 1928 and 1929

Materials	1928			1929			Ave. price
	Pits	*tons*	*value*	Pits	*tons*	*value*	
Sand							
Molding	5	64,929	$ 43,667	3	48,558	$ 32,911	$ 0.68
Building	38	531,400	280,843	39	442,491	224,833	.51
Paving and roads	38	1,088,377	450,712	42	1,294,148	538,416	.42
Grinding, polishing	3	14,087	31,789	3	18,676(b)	41,050	
Engine	10	35,608	17,163	10	44,338	22,146	.50
Filter	1	(a)					
R. R. ballast	3	10,660	3,060	3	26,345	5,726	.22
Other	3	88,737	45,370	7	12,723	2,965	.23
Total sand	60	1,833,798	872,604	62	1,887,279	868,047	
Gravel							
Building	38	341,533	333,079	40	317,719	254,666	.80
Paving and roads	43	1,013,941	790,344	44	1,600,895	973,893	.61
R. R. ballast	12	228,529	83,703	7	224,204	93,587	.42
Other	5	5,818	15,225	4	13,572	21,559	1.60
Total gravel	64	1,589,821	1,222,351	64	2,156,330	1,343,705	
Total output	80	3,423,619	2,094,955	80	4,043,609	2,211,752	.55

(a) Included in Other sand.
(b) Includes filter sand, average price $2.74; blast sand, average price $2.03.

Production of sand and gravel throughout the nation was the highest in its history, the gain over 1928 amounting to 6.4 per cent. The same trends—downward in the case of structural material and upward in case of road making and ballast—were evident in national production as in our own state. The largest producers were as shown in the following list:

State	*Tons*	*Value*
New York	21,061,094	$ 14,919,658
Illinois	18,256,203	9,071,258
Michigan	16,844,099	7,928,744
California	15,688,545	8,371,263
Ohio	14,250,141	9,182,862
Pennsylvania	12,674,320	13,658,328
Indiana	10,901,798	5,528,832
Wisconsin	10,727,632	4,574,182
Texas	9,409,295	5,765,943
New Jersey	6,721,498	5,585,285
Total for U. S.	222,571,905	$132,835,979

Iowa ranked fifteenth in production and sixteenth in value.

Production of Sand and Gravel in 1929—Sand

Counties	Pits	Structural sand		Paving sand		Other sand (a)		Total sand	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Allamakee (0), Clayton (1), Fayette (1), Winneshiek (2)........	4	....	....	69,655	$ 56,072	(c)	....	69,655	$ 56,072
Black Hawk(3), Floyd(1), Tama(1)	5	54,455	$ 32,959	49,460	28,906	(c)	....	128,471	76,073
Boone(1), Marshall(2), Story(0)...	3	22,939	12,095	22,668	11,298	(c)	....	45,607	26,993
Butler........................	3	15,222	5,262	76,189	19,388	(c)	....	91,411	24,650
Cerro Gordo(2), Franklin(0), Hancock (1).....................	3	72,500	31,750	155,068	54,653	12,500	$ 5,250	240,068	90,056
Clinton........................	3	41,927	17,377	28,386	6,673	....	....	70,313	24,050
Crawford (0), Harrison (1), Plymouth (1)..................	2	(b)	....	(d)	....	....	....	(g)	....
Dallas(0), Mahaska(1), Marion(2).	3	(c)	....	180,950	89,852	....	....	180,950	89,852
Des Moines (2), Lee (2)..........	4	12,737	5,740	20,223	8,040	(c)	....	32,960	13,780
Dubuque (2), Jackson (1)........	3	(c)	....	101,547	29,071	....	....	101,547	29,071
Emmet(1), Osceola(1), Palo Alto(2)	4	8,303	6,393	....	....	(f)	....	8,303	6,193
Humboldt (1), Pocahontas (1), Webster (1), Wright (1)........	4	6,460	3,290	79,705	21,413	(c)	....	86,365	24,703
Johnson(1), Linn(2), Scott(1).....	4	24,315	19,115	129,877	80,764	9,192	4,019	160,384	100,398
Lyon (1), Sioux (3)..............	4	(c)	....	167,716(e)	92,619	(c)	....	167,716	92,619
Muscatine......................	4	82,636	41,494	118,079	30,034	34,230	49,541	234,945	121,069
Polk...........................	5	56,583	27,250	129,520	64,953	(c)	....	186,103	92,203
Sac............................	4	(c)	....	124,954	47,407	....	....	124,954	47,407
Total........................	62	442,491	224,833	1,294,148	538,416	150,640	104,798	1,887,279	868,047
Totals for 1928...............	60	531,400	280,843	1,088,377	450,712	214,021	141,049	1,833,798	872,604

(a) Includes: Molding, grinding, polishing, blast, engine, filter, ballast, other sands.
(b) Included with structural gravel.
(c) Included with paving sand.
(d) Included with paving gravel.
(e) Includes paving gravel.
(f) Included with structural sand.
(g) Included with total sand and gravel.

Production of Sand and Gravel in 1929—Gravel

Counties	Pits	Structural gravel		Paving and other gravel (h)		Total sand and gravel		Total quantity washed	
		tons	*value*	*tons*	*value*	*tons*	*value*	*tons*	*value*
Allamakee (1), Clayton (0), Fayette (1), Winneshiek (2)	4	12,718	$ 8,210	74,968	$ 40,031	157,331	$ 104,321	127,976	$ 83,062
Black Hawk(2), Floyd(0), Tama(1)	3	10,136	13,716	28,585	27,768	142,636	103,349	127,043	94,109
Boone (2), Marshall (2), Story (2)	6	14,833	12,401	144,580	21,800	211,322	63,646	66,062	41,496
Buena Vista (2), Dickinson (1)	3	(d)	....	139,739	29,763	139,739	29,763	....	....
Butler	3	(d)	....	283,005	116,774	374,416	141,424	221,412	125,902
Cerro Gordo(2), Franklin(1), Hancock (1)	4	20,100	23,550	177,568	163,653	435,736	278,856	382,500	271,500
Clinton	5	72,613	37,638	75,936	40,100	218,862	101,788	196,208	82,863
Crawford (2), Harrison (1), Plymouth (1)	4	8,386(i)	5,436	60,386(j)	21,986	68,772	27,422	....	....
Dallas(1), Mahaska(1), Marion(1)	3	(d)		220,186	170,055	401,136	259,907	366,636	242,657
Des Moines (2), Lee (1)	3	15,548	12,903	(b)	....	48,508	26,683	34,158	18,161
Dubuque (2), Jackson (1)	3	31,139	15,830	118,920	85,209	251,606	130,110	193,086	119,930
Emmet(1), Osceola(1), Palo Alto(2)	4	1,617	240	36,213	6,764	45,133	13,197	....	....
Humboldt (1), Pocahontas (1), Webster (1), Wright (1)	4	11,017	10,792	76,272	44,100	173,689	79,595	94,404	70,537
Johnson(1), Linn(0), Scott(1)	2	....	....	(c)	....	163,384	103,898	162,384	102,898
Lyon (0), Sioux (1)	1	....	....	(c)	....	167,716	92,619	131,000	82,400
Muscatine	4	19,399	13,310	149,656	121,755	435,220	282,175	435,220	282,175
Polk	4	31,845	39,881	35,064	40,693	253,012	172,877	253,012	172,877
Sac	5	22,120	15,105	204,472	137,318	352,381	200,122	280,027	190,217
Totals	64	317,719	254,666	1,838,611	1,089,039	4,043,609	2,211,752	3,089,611	1,992,835
Totals for 1928	64	341,533	333,079	1,248,288	889,272	3,423,619	2,094,955	2,847,553	1,873,539

(b) Included with structural gravel.
(c) Included with paving sand.
(d) Included with paving gravel.
(h) Includes: Paving and roadmaking, railroad ballast, other gravels.
(i) Includes structural sand.
(j) Includes paving sand.

The following is a list of sand and gravel producers in Iowa:

Allamakee County
- Northeastern Iowa Sand & Gravel Co., Harpers Ferry

Black Hawk County
- Concrete Materials Corp., 504 Lafayette Bldg., Waterloo
- Iowa Foundry Sand Co., 106 Western Ave., Waterloo
- Waterloo Dredging Co., 85 W. Mullen, Waterloo
- Waterloo Sand & Gravel Co., C. H. Werner, P. O. Box 553, Waterloo

Boone County
- McHose Sand & Tile Co., Boone. Pit at Fraser
- Markey River Sand Co., R. B. Markey, Boone

Buena Vista County
- Buena Vista Highway Dept., care of County Engineer, Storm Lake
- L. L. Walton, Linn Grove
- Chicago & North Western Ry. Co., 226 W. Jackson St., Chicago, Ill. Pit at Sioux Rapids

Butler County
- Concrete Materials Corp., 504 Lafayette Bldg., Waterloo. Pit at Clarksville
- Aplington Cement Tile & Block Works, Chas. Willeke, Aplington
- Waverly Gravel & Tile Co., Waverly. Pit at Shell Rock

Calhoun County
- Calhoun County Highway Dept., Rockwell City

Carroll County
- Chicago Great Western R.R. Co., 122 S. Mich. Blvd., Chicago, Ill. Pit at Lanesboro

Cerro Gordo County
- Clear Lake Sand & Gravel Co., Clear Lake
- Ideal Sand & Gravel Co., Mason City
- Chicago, Mil., St. P. & P. R. R. Co., New Union Sta., Chicago, Ill. Pit at Plymouth

Cherokee County
- Harris & Loucks Gravel Co., Cherokee
- Illinois Central Ry. Co., Chicago, Ill. Pit at Cherokee
- Iowa Gravel Products Co., M. R. Gibbons, 3330 Maynard St., Cleveland, Ohio. Pit at Cherokee
- Northwestern Gravel Co., Lake View. Pit at Cherokee

Clay County
- John F. Stolley, Spencer
- Spencer Cement Block Works, Lock Box 344, Spencer

Clayton County
- Clayton White Sand Co., Clayton
- Langworthy Silica Co., 902 Federal Bank Bldg., Dubuque. Pit at Clayton
- State Highway Dept., Ames. Pit at Osborne

Clinton County
- Clinton County, care of County Engineer, Clinton
- Clinton Sand & Gravel Co., E. A. Schultz, Pres., 604 Wilson Bldg., Clinton
- Camanche Sand & Gravel Co., United Light Bldg., Davenport
- Schneider Sand & Gravel Co., Clinton
- Jenner Bros., 320 First Natl. Bank, Davenport. Pit at De Witt
- A. F. Barber, R. D. 2, Grand Mound

Crawford County
- Crawford County, care of County Engineer, Denison
- Hannah Carlson, Kiron

Dallas County
- Commercial Sand Co., & Portland Sand & Gravel Co., 513 Youngerman Bldg., Des Moines. Pit at Booneville
- Coon River Sand Co., 218 9th St., Des Moines. Pit at Van Meter

Des Moines County
- Kelley Sand & Fuel Co., R. J. Dietlein, Burlington. Pit near Oquawka, Ill.
- Burlington Sand & Gravel Co., Burlington

Dickinson County
- Chicago, Mil., St. P. & P. R. R. Co., New Union Sta., Chicago, Ill. Pit at Milford

Dubuque County
- Iowa Gravel & Fuel Co., Inc., 501 Garfield Ave., Dubuque
- Chicago, Mil., St. P. & P. R. R. Co., New Union Sta., Chicago, Ill. Pit at Dubuque
- Molo Sand & Gravel Co., Foot of 3d St., Dubuque

Emmet County
- Wm. Stuart, Armstrong
- Atwood, Korrect & Stewart, Armstrong. Pit at Estherville
- Cement Products Co., Estherville
- Chicago, R. I. & Pac. Ry. Co., La Salle St. Sta., Chicago, Ill.

Fayette County
- Clermont Brick & Sand Co., Clermont

Floyd County
- Iowa Foundry Sand Co., Waterloo. Pit at Floyd

Chicago, R. I. & Pac. Ry. Co., La Salle St. Sta., Chicago, Ill. Pit at Marble Rock

Franklin County

W. C. Nolte, Sheffield

Hancock County

Hancock County Highway Dept., Garner

Hardin County

Chicago & N. W. Ry. Co., 226 W. Jackson St., Chicago, Ill. Pit at Gifford

Minneapolis & St. Louis R. R., Minneapolis, Minn. Pit at Gifford

Harrison County

Rogers Brothers, Dunlap

M. B. Musgrave, Woodbine

McDougal Constr. Co., Sioux City

Humboldt County

Humboldt Gravel & Tile Co., Humboldt

Jackson County

Bellevue Sand & Gravel Co., L. E. Duvall, Mgr., Bellevue

Chicago, Mil., St. P. & P. R. R. Co., New Union Sta., Chicago, Ill. Pit at Smiths

Johnson County

Hawkeye Material Co., P. O. Box 104, Iowa City

Schmidt Sand & Gravel Co., R. F. D. 4, Iowa City

W. Stock, River Junction

Jones County

Chicago, Mil., St. P. & P. R. R. Co., New Union Sta., Chicago, Ill. Pit at Monticello

Lee County

Jos. Jaeger, Montrose. Pit at Fort Madison

Keokuk Sand Co., Ft. of Bank St., Keokuk

Linn County

Kings Crown Plaster Co., 98 First Ave. W., Cedar Rapids

Larimer & Shaffer, 931 North 1st St., W., Cedar Rapids

Ed. Sigfred, Marion. Pit at Springville

Louisa County

State Highway Dept., Ames. Pit at Oakville

Lyon County

Great Northern Ry. Co., St. Paul, Minn. Pit at Doon

Miller Sand & Gravel Co., Box 101, Doon

Chicago, Rock Island & Pacific Ry. Co., La Salle St. Sta., Chicago, Ill. Pit at Granite

Mahaska County

Concrete Materials Corp., W. W. Reilly, Eddyville

Marion County

Harvey Sand & Gravel Co., Harvey

Wilson Sand & Gravel Co., Harvey. Pit at Tracy

Marshall County

Empire Sand & Material Co., A. L. Keller, Lock Box 467, Marshalltown. Pit at Keller

R. M. Hawkins, 1110 N. 3d Ave., Marshalltown

Mitchell County

J. C. B. McIntire, McIntire

Burton Stacy, Osage

Muscatine County

Chicago, Rock Island & Pacific Ry. Co., La Salle St. Sta., Chicago, Ill. Pit at Fruitland

Automatic Gravel Products Co., Box 34, Muscatine

Hahn Brothers Sand & Gravel Co., 207 W. Front St., Muscatine

C. A. Hagermann, Muscatine

Northern Gravel Co., Muscatine

Pearl City Gravel Co., Ed. L. Hahn, Muscatine

Osceola County

Chicago, Rock Island & Pacific Ry. Co., La Salle St. Sta., Chicago, Ill. Pit at Sibley

Palo Alto County

County Highway Dept., Emmetsburg

Chicago, Rock Island & Pacific Ry. Co., Chicago, Ill. Pit at Graettinger

Graettinger Tile Works, Graettinger

State Highway Dept., Ames. Pit at Osgood

Plymouth County

Big Sioux Gravel Co., Akron

Albert A. Wenzel, Kingsley. Pit at Pierson

Pocahontas County

Pocahontas County Highway Dept., care of County Engineer, Pocahontas

Polk County

Chicago, Rock Island & Pacific Ry. Co., La Salle St. Sta., Chicago, Ill. Pits at Avon and Commerce

Des Moines & Central Iowa R. R. Co., Des Moines

Commerce Sand & Gravel Co., G. N. Doty, Pres., Box 4, Commerce

Capital City Sand Co., 1111 29th St., Des Moines

Coon River Sand Co., 501 Hubbell Bldg., Des Moines

The Des Moines Sand & Fuel Co., 510 Grand Ave., Des Moines

Hawkeye Co-operative Sand & Gravel Co., John Keefner, Pres., 822 W. 9th St., Des Moines
N. Leon Harris, R. R. 4, Lock Box 507, Des Moines
Independent Sand & Gravel Co., 325 S. W. 7th St., Des Moines
Flint Crushed Gravel Co., Des Moines. Pit at Granger
Portland Sand & Gravel Co., & Commercial Sand Co., 513 Youngerman Bldg., Des Moines
O'Rourke Constr. Co., Des Moines

Sac County
LeGrand Crushed Rock & Gravel Co., Lake View
Chicago & N. W. Ry. Co., 226 W. Jackson St., Chicago, Ill. Pit at Lake View
Wm. Brauer, R. F. D. 1, Lake View
Northwestern Gravel Co., Lake View
LeGrand Limestone Co., 29 S. La Salle St., Chicago, Ill. Pit at Sacton (Lake View)
Mrs. Nils Miller, Sac City
Sac County, Office of Engr., Sac City
W. H. Schnirring, Sac City
Mrs. W. H. Townsend, Sac City

Scott County
Scott County, Office Engr., Davenport
Builders Sand & Gravel Co., 626 W. Front St., Davenport. Pit at Buffalo
Chicago, Rock Island & Pacific Ry., La Salle Sta., Chicago, Ill. Pit at Buffalo
W. G. Block Co., 319 E. Fourth St., Davenport

Sioux County
D. A. Sorgdrager, R. D. 1, Alton
Alton Cement Works, C. Vandermeer, Alton
L. G. Everist, Inc., 2100 E. 4th St., Sioux City. Pit at Hawarden
Hawarden Gravel Co., Hawarden
Schemmer Sand & Gravel Co., Rock Valley
Rock Valley Sand & Gravel Co., Rock Valley

Story County
Ames Sand & Gravel Co., Ames
R. E. Carr Sand & Gravel Co., E. 16th St., Ames
Story County, Office of County Engineer, Nevada. Pit at Ames
H. R. Maudlin, 414 J Ave., Nevada
Roy Templeton, Ames

Tama County
Standard Gravel Co., 907 Bankers Tr. Bldg., Des Moines. Pit at Tama

Wapello County
Ottumwa Sand Co., Ottumwa

Webster County
Johnston Clay Works, Inc., Ft. Dodge. Pit at Clayworks

Winneshiek County
E. W. Hallett & Co., Decorah
Ward & Taylor Constr. Co., Decorah

Wright County
Belmond Cement Mfg. Co., Belmond
Luick Gravel Co., Belmond
Chicago, R. I. & Pacific Ry. Co., 902 La Salle St. Sta., Chicago, Ill. Pits at Belmond
Chicago Great Western R. R. Co., Chicago, Ill. Pit at Belmond

THE CLARINDA OIL PROSPECT

On November 5, 1928, Iowa's First Oil Developing Co., of Clarinda, Iowa, began an oil prospect on the Wilson farm, in the bottoms of Nodaway river, about four miles south of Clarinda, in the SE. ¼, SE. ¼, Sec. 24, T. 68 N., R. 37 W., Page county. Elevation of curb 988 feet. The drillers were G. H. Rose and Son of Maryville, Mo. Work was abandoned December 8, 1930. Although neither oil nor gas was found in quantity the drilling has aroused much interest, and a summary of the strata penetrated is given here. A more complete report will be published later.

Strata		*Depth*	*Thickness*
Pleistocene and Recent—clay	0	–25	25
Pennsylvanian			
Missouri			
Shawnee—limestone and shale	25	–140	115
Douglas—limestone and shale	140	–375	235
Lansing—limestone and shale	375	–540	165
Kansas City—limestone and shale	540	–660	120
Des Moines			
Pleasanton and Henrietta—limestone and shale	660	–920	260
Cherokee—sandstone and shale	920	–1,610	690
Mississippian			
Meramec—limestone	1,610	–1,765	155
Osage—limestone and shale	1,765	–1,858	93
Chouteau—limestone	1,858	–1,895	37
Kinderhook—limestone and shale	1,895	–2,016	121
Devonian—limestone	2,016	–2,101	85
Silurian—limestone and dolomite	2,101	–2,555	454
Ordovician			
Maquoketa—shale, some dolomite	2,555	–2,595	40
Galena—dolomite, some shale	2,595	–2,945	350
Decorah—shale and dolomite	2,945	–2,992	47
St. Peter—sandstone and dolomite	2,992	–3,067	75
Shakopee—dolomite	3,067	–3,124	57
New Richmond—sandstone	3,124	–3,162	38
Oneota—dolomite	3,162	–3,313	151
Cambrian			
Jordan—sandstone	3,313	–3,340	27
Bonneterre, Eau Claire—dolomite	3,340	–3,554	214
LaMotte, Mount Simon—sandstone	3,554	–3,570	16
Red Clastics or Sioux Quartzite—sandstone or quartzite	3,570	–4,671	1,101